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Technical Report NR 197-019

EFFECTS OF LONG-DURATION COLD EXPOSURE ON PERFORMANCE OF TASKS IN NAVAL INSHORE WARFARE OPERATIONS

W. S. Vaughan, Jr.
Birger G. Andersen

Contract No. N00014-72-C-0309

Prepared for:

Engineering Psychology Programs
Psychological Sciences Division
Office of Naval Research
Arlington, Virginia 22217

Prepared by:

OCEANAUTICS, Inc.

3308 Dodge Park Road
Landover, Maryland 20785

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N R - 197-019

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Oceanautics, Inc. 3308 Dodge Park Road Landover, Maryland 20785	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b GROUP

3 REPORT TITLE

Effects of Long-Duration Cold Exposure on Performance of Tasks in Naval Inshore Warefare Operations

4 DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(Last name, first name, initial)*

Vaughan, Willard S., Jr.
Andersen, Birger G.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1973	116	10

8a. CONTRACT OR GRANT NO. N00014-72-C-0309	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. NR 197-019	
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d	

10. AVAILABILITY/LIMITATION NOTICES

~~Distribution limited to U.S. Government agencies only; Test and Evaluation; 1 November 1973. Other requests for this document must be referred to Chief of Naval Research (Code 455).~~

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Office of Naval Research - Code 455 Naval Ships System Command - 00C

13. ABSTRACT Eight UDT and SEAL Team personnel participated in a series of 6-hour test scenarios composed of 3-hours in water, 1-hour in air and 2-hours in water. A variety of tasks were performed in the water which were simulations of submersible operator and navigator tasks: depth and heading control, obstacle detection and avoidance, and navigation problem-solving. In -air tasks were simulations of a demolition raid on an inland target. Test scenarios were run in both cold and control temperature conditions. Cold exposure consisted of water temperature of 4.5°C. (40°F.) and air temperature of 10°C. (50°F.); control exposure temperatures were 15.5°C. (60°F.) water and 20°C. (68°F.) air. Following the 6-hour exposures, divers rewarmed in either a hot-water bath at 40°C. (104°F.) or in a hot-air van at 38°C. (100°F.). Three skin temperatures, core temperature and ECG records were taken throughout the exposure and rewarming phases.

Results suggest a first-hour distraction effect of extreme temperature conditions on performance of vigilance and problem-solving tasks. In cold water, performance was significantly degraded relative to the moderate temperature during the first hour's exposure, then recovered to a level of effectiveness comparable to that associated with the moderate temperature. All tasks showed a gradual decrement with time in the water. In-air task performance was less effective following the 3-hour water exposure for both manual and mental tasks.

DD FORM 1 JAN 64 1473

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Cold Stress						
Diver Performance						
Submersibles						
Physiological Monitoring						

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13. Abstract - continued

Hot air rewarming doubled the time required for core temperature to return to normal but was equally effective as the hot water bath method in minimizing extent of post-dive fall in core temperature.

ACKNOWLEDGMENTS

This report documents a cold water test project whose training and data collection phases were carried out at Naval Weapons Center, China Lake, California, between 10 July and 17 November 1972. The project was sponsored jointly by the Engineering Psychology Programs, Office of Naval Research, and the Naval Ship Systems Command, and was carried out under Contract N00014-72-C-0309. Mr. Gerald S. Malecki and Dr. Martin A. Tolcott of ONR, and LCDRs Cathal L. Flynn and Irve C. LeMoyne of NAVSHIPS have given this project and the general program of performance measurement in Naval Inshore Warfare operations their long-term and very much appreciated interest, encouragement and support.

At the Naval Weapons Center, Mr. K. W. Specht, Head, Swimmer Vehicle Branch and his administrator, Mr. J. D. Whitfield, generously provided facilities, materials, personnel and coordination in support of the project. The authors are indebted to many at NWC and particularly to Mr. J. Childress, who maintained the simulation equipment systems, Mr. D. Bymoen and Mr. J. Lopez who installed and calibrated the recording system, and LCDR A. H. Spinks who provided needed items of operational equipment and served as a focal point for military coordination.

Test divers, diving officer and corpsman for the project were provided by Naval Special Warfare Group, Pacific. The authors thank CDR David Del Guidice, Chief Staff Officer of NAVSPECWARGRU ONE, whose support enabled the project to be accomplished; and Lt(jg) D. J. Glasser of SEAL ONE who was the officer in charge, and who served as diving officer throughout the training and testing phases of the project.

Medical support during the long-exposure test dives was provided by LCDR M. B. Strauss, U.S. Naval Hospital, San Diego, and by LCDR W. Craver, SUBDEVGRU ONE. H. W. Koester, HMC, was chief petty officer and corpsman throughout the test series.

Special simulation and monitoring equipment systems were developed for use in the project and the authors express their appreciation to a number of persons in this regard. Mr. Allan Slater, of Emergency Care Research Institute, Philadelphia, designed the navigation display simulator and the physiological monitoring equipments. Mr. J. F. Byers of Applied Research Laboratory, University of Texas, designed the obstacle avoidance system display simulator. Lloyd Savoie, FTCS of NAVSPECWARGRU ONE designed the SDV control/display simulator. Dr. Glen Egstrom, UCLA, graciously loaned us a bicycle ergometer from his laboratory.

Finally, with much appreciation, the authors thank Mr. John S. Swider for his substantial contributions to all aspects of implementation.

ABSTRACT

A 6-hour test scenario was developed to determine effects of long-duration cold exposure on performance of tasks representative of Naval Inshore Warfare operations involving Swimmer Delivery Vehicles (SDVs). The test scenario was composed of three phases: 3-hours in water, 1-hour in air, and 2-hours in water. During the water phases, test divers performed tasks representative of an SDV pilot and navigator; during the air phase, they performed tasks representative of an inland demolition raid. The test scenario was run under two conditions of exposure: a cold condition, where water temperature was 4.5°C (40°F) and air temperature was 10°C (50° F), and a control condition where water and air temperatures were 15.5°C (60°F) and 20°C (68°F) respectively. Two rewarming methods were compared as test divers rewarmed in a hot water bath, and in a hot air van.

Test divers were instrumented for underwater physiological monitoring. Throughout the 6-hour test scenario and the rewarm phase, records were taken of three physiological variables: skin temperature, core temperature and heart rate. Skin temperatures were recorded from three sites: upper arm, medial thigh and mid-back. Core temperature was taken via radio-sonde pills swallowed by the divers. Heart rates were read from an electrocardiogram record.

Signal generation of operator and navigator in-water task input was provided by simulation equipment mounted in a MK VII SDV hull. Pilot tasks included vehicle control and obstacle avoidance. Specific measures of pilot performance were heading deviation, depth deviation, signal detection percentage, signal acquisition latency, and choice reaction accuracy. The navigator's task involved the solution of current-vector problems; problem-solving accuracy, solution time, and frequency of omission measures were taken. In-air tasks included strength tests, map problem-solving, and apparatus assembly.

Test divers were eight enlisted men of UDT and SEAL team units of Naval Special Warfare Group, Pacific. Prior to test operations, a three-month training program was conducted wherein each diver received 14 hours of training in the pilot tasks, 20 hours in the navigator task, and 15 hours in the demolition raid tasks. Training included habituation to cold water. Each test diver experienced 32 hours of in-water training, 12 in 60° F water and 20 in 50°F water.

Hour-to-hour task performance profiles were examined in relation to hour-to-hour changes in physiological descriptors, principally core temperature, for both cold and control exposure conditions. In-water task performance profiles exhibited a characteristic pattern of gradual decrement as a function of time, but there were few differences in performance as a function of exposure temperature differences, except during the first hour. Each performance dimension tended to reflect significant decrement in the first hour in 40°F water vis-a-vis 60°F water. This first-hour performance effect occurred in the absence of differences in core temperature. Omission of component parts of problem-solving task requirements occurred only in the colder water and only in the later hours of the test scenario. In-air task performance effectiveness, measured after the 3-hour water exposure, was significantly reduced as compared to baseline values; but performance level was not affected by differences in exposure conditions or differences in mean core temperatures at the time of performance: 36.3° vs 36.2°C. Decrements in performance on strength tests measured upon water-exit substantially recovered within one hour.

Differences in rewarming methods did not affect extent of post-dive fall in core temperature, given identical exposure conditions. Time to recovery to normal core temperature in the hot-air method, however, was approximately double the recovery time in hot water.

Relationships between task performance and long-duration cold exposure were interpreted as a three-stage process involving concepts of distraction, discomfort, and dysfunction.

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I. INTRODUCTION

A. Background and Purpose

The context of this research was a generalized long-duration, cold water operation of a Navy, manned, wet submersible; and the main areas of concern were the performance and physiological consequences of the environmental stresses associated with this context. Previous research (Vaughan, 1969; Vaughan and Swider, 1972) has focused on specific mission profiles for the MK VII Swimmer Delivery Vehicle (SDV) in exposures ranging to six hours duration at a water temperature of 6°C (43°F). These studies suggested that degradation in performance was a complex function of variables which included task type and task load. The primary purposes of the present research, therefore, were to determine the effects of long-duration cold exposure on an expanded range of task areas, particularly to include those of a more cognitive character; and to examine the effects of cold exposure under conditions of increased task loading on the submersible operator.

A second area of interest was stimulated by the finding that increasing the duration of exposure to cold water increased the magnitude of the post-dive fall in core temperature during rewarming. Cold-water dives at Keyport, Washington (Vaughan & Swider, 1972) had shown that the mean fall in core temperature progressed from 0.1°C to 0.3°C to 0.4°C following 4-, 5- and 6-hour exposures to 6°C water. These reductions occurred while the divers were rewarming fully immersed in a hot water bath at 40° C (104° F). Since facilities for this ideal method of rewarming a cold diver (Keatinge, 1969) were not commonly available at operational diver recovery sites, the effects of a more conventional, warm-air rewarming method on post-dive fall of core temperature was to be determined.

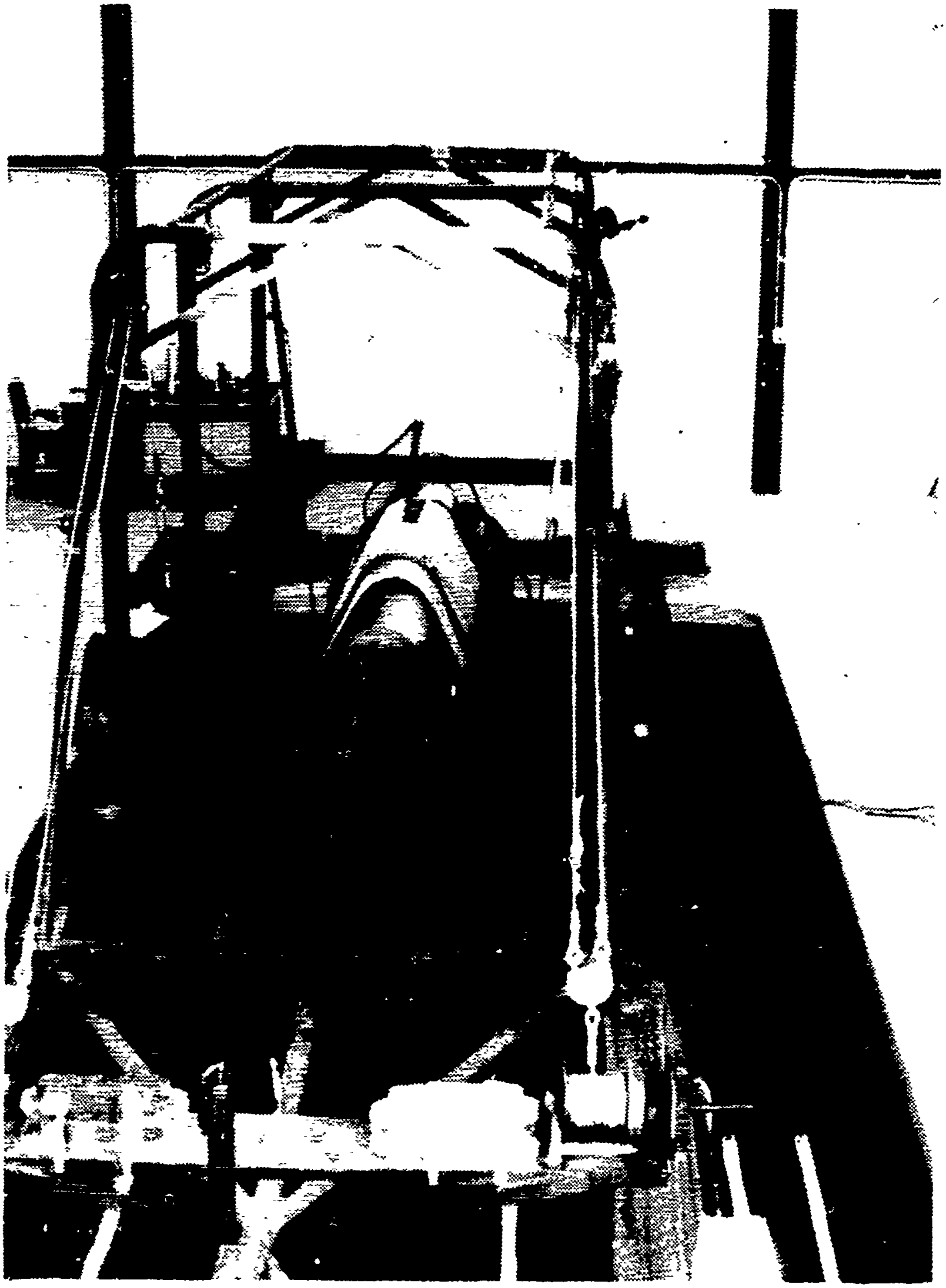
A third purpose was to explore the physiological and performance consequences of transitioning to an air environment, and doing tasks on land following a relatively long, cold-water transit in a wet submersible.

B. Facilities and Test Conditions

The study was conducted at the Naval Weapons Center, China Lake, California, using the cold water test facilities of the Swimmer Vehicle Branch. The main test facility was an air conditioned building which included a refrigerated pool eight feet deep and large enough to accommodate a MK VII SDV configured as a simulator. Adjacent to the main test building were a hot water rewarming tank and a hot air rewarming van. A second van was used for diver dressing and instrumentation; a third van housed the simulation control, monitoring, and recording equipment. Figure 1 shows the SDV simulator positioned over the refrigerated pool in the main test building. The SDV was suspended within the frame of a trailer, and the trailer was wheeled on to H-beams which traversed the length of the pool. Winches enabled the SDV to be lowered into and raised from the eight-foot deep pool.

The in-water phases of the test scenario were conducted in the pool at a water depth of approximately five feet. The water was still and clear, and visibility was standardized by the building illumination. The test divers worked in pairs seated in the MK VII SDV simulator. They wore the individually-tailored SDV SUIT # 2000 manufactured by Diving Unlimited, San Diego, California. This combination included a 1/4-inch "Farmer John" overall, an 1/8-inch hip length vest with attached hood, a 1/4-inch jacket with attached hood, 1/4-inch soft-soled boots, and 3-fingered mittens of 3/8-inch neoprene with 1/4-inch over the palm. The material was

Figure 1. Swimmer Delivery Vehicle Simulator
and Cold Water Test Pool



nitrogen-blown neoprene rubber with nylon on one side only. The suits were zipperless and the rubber side of each piece was worn toward the skin. Breathing gas was compressed air, demand-supplied to a full face mask. A hard wire communication system connected the divers, and their conversation was monitored by a safety diver at poolside.

The main experimental conditions were the exposure temperatures and the rewarming methods. The overall 6-hour test scenario included a 3-hour water phase, a 1-hour air phase, and a 2-hour water phase. In the cold stress condition, water and air temperatures were 4.5°C (40°F) and 10.0°C (50°F) respectively. In the control condition these values were 15.5°C (60°F) and 20.0°C (68°F). Each diver made two runs in each condition, and the divers rewarmed in a hot bath at 40°C (104°F) following the first run, and in a hot air van at 38°C (100°F) following the second run.

C. Test Divers

The test divers were eight UDT and SEAL team enlisted volunteers from Naval Special Warfare Group One. Table 1 presents descriptive characteristics of these men. In addition to the test divers, these units provided a diving officer, a corpsman, and two men who served as problem controllers and data collectors.

Table 1. Test Diver Characteristics

Test Diver	Unit	Rate	UDT Training Class	Age	Height (inches)	Weight (pounds)	Body Fat (%)
1	UDT-11	SF3	Feb. 70	24	68	147	11.6
2	UDT-11	GMG1	May 67	28	74	211	14.0
3	UDT-12	SN	June 70	21	68	168	12.0
4	UDT-12	QMSN	June 71	22	73	191	13.9
5	SEAL ONE	GMG3	Sept. 69	22	71	170	12.2
6	UDT-12	ML3	June 70	23	68	170	12.3
7	UDT-11	SN	Mar. 72	20	67	154	12.1
8	SEAL ONE	GMG3	Nov. 69	22	71	181	12.9

II. METHOD

A. Tasks and Training

Selection and development of tasks for inclusion in the test scenario were guided by two general criteria: the tasks should tap a range of basic human capabilities, and they should be representative of the kinds of tasks required in UDT/SEAL operations with Swimmer Delivery Vehicles. A generalized and hypothetical demolition raid on an inland target by an SDV-delivered SEAL patrol was used as an operational context for task selection and scenario development. The generalized mission was envisioned in three phases: a 3-hour SDV transit to a delivery area, a 1-hour raid, then a 2-hour transit in the SDV to a recovery area. The test divers would function as an SDV crew during the in-water phases, and as a SEAL patrol during the in-air phase. Tasks, therefore, were selected and grouped into subsets representing the tasks required of an SDV pilot, an SDV navigator, and a SEAL patrol on a demolition raid.

1. SDV pilot tasks. The SDV pilot was assigned two main functions: vehicle control and obstacle avoidance. Vehicle control involved continuous and simultaneous stick adjustments for heading and depth. Left/right stick movement controlled heading; fore/aft stick adjustments controlled depth. During each hour of the in-water phases, the pilot steered a series of three 20-minute headings and held a prescribed depth. Obstacle avoidance involved continuous scanning of an obstacle avoidance system (OAS) display, detection of obstacle signals, and a maneuver response appropriate to the location of the obstacle. The number of obstacles presented each hour ranged from six to nine.

In terms of basic abilities, this subset of tasks included dual compensatory tracking, vigilance-monitoring, and choice reaction. Fleishman (1964) has identified factor dimensions of psychomotor abilities and the pilot task subset fits his definitions of control precision and response orientation.

2. Navigator tasks. The SDV navigator was assigned an underwater navigation function; therefore, tasks and task equipments were developed which represented the operation of a Doppler-like navigation system where the navigator, rather than automated equipment, performed the computations. A detailed description of this task and related equipment and procedures is presented in Appendix A. Essentially, the equipment provided a real-time display of data from which the navigator could construct a vector triangle and determine set and drift of the current, SDV speed and course over the bottom, and a new SDV heading that corrected for the current. The navigational problem-solving task involved procedures-following, data observation and recording, measurement and calculation. For each leg steered by the pilot, the navigator was required to solve a vector problem.

3. Patrol tasks. Basic performance requirements of an SDV-delivered attack team included use of cable or wire cutters, running with a 40-pound load to an objective 1000 yards inland, installing a demolition pack, rigging a firing device, and running back to the rendezvous point for pickup. From these requirements, three specific tests were abstracted: 2-hand compression strength, hand-grip strength, and finger dexterity. A fourth task was added, map problem-solving, in order to include a cognitive exercise in the in-air phase of the test scenario. The map problem was an abstract representation requiring time/distance/rate calculations and compass-bearing determinations along component legs from the point of entry to the objective and return.

4. Training stages. Prior to the test program, each diver was given 49 hours of training in the tasks and the procedures of the test scenario. A fourteen-week training program was conducted in four stages. The first stage consisted of classroom lecture, demonstration and practice in the radio firing

device (RFD) procedure, the map and the vector problem-solving procedure. Stage two was the development of, and practice in, the in-air phase of the test scenario. Stage three was the in-water training of the SDV pilot and navigator, first independently and then as a coordinated SDV crew. These sessions were conducted in 60°F (15.5°C) water. The fourth and final stage was the integration of water and air phases into an overall test scenario. This stage of training was implemented in two parts: short-duration runs of 2.5 hours, and long-duration runs of 4.5 hours. Water temperature during this stage of training was lowered to 50°F (10°C).

Table 2 presents a summary of the number of hours of training given each test diver during each stage.

B. Instrumentation and Measurement

1. Physiological monitoring. On all test runs, both divers were instrumented for skin temperature, core temperature, and ECG monitoring. The displays associated with this equipment were located at poolside in the main test building, and they were monitored continuously by either the corpsman or the diving medical officer. Three skin temperatures, core temperature and heart rate were recorded at 10-minute intervals throughout the 6-hour test scenario. Core temperature was recorded at 5-minute intervals during the rewarming phase.

a) Skin temperature. Skin temperatures were taken from three sites on each diver: medial thigh, mid-back, and upper arm. The sensors were mounted thermistor assemblies, Model #403, manufactured by Yellow Springs Instrument Company. Sensor accuracy was ± 0.1°C absolute. Each thermistor assembly was molded to a waterproof cable which terminated in an Electro-Oceanics underwater connector. The connector plugs were coded to indicate sensor location on the body. The connectors were joined to a waterproof junction box which contained the receiver and signal-

Table 2. Hours of Training per Task Area

	Classroom Lecture			In-Air Scenario Training	In-Water SDV Training		Integrated Scenario Training		
	RFD	Vector Problem	Map Problem	Integration of In-Air Tasks	Equipment Operation	Crew Coordination	Short Duration	Long Duration	Totals
SDV Pilot Tasks					3	3	4	4	14
SDV Navigator Tasks		6			3	3	4	4	20
Patrol Tasks	3		6	3			2	1	15

processing electronics. Leads carried the signals from the junction box to the meter readouts at poolside, where the readouts were calibrated in 0.25°C unit~~s~~ between 0.0° and 35.00°C.

b) Core temperature. Core temperature data were obtained by means of a temperature-sensitive endoradiosonde pill; a paraffin-coated, disc-shaped teflon capsule approximately 0.4-inch in diameter and 0.2-inch in thickness. The capsule housed a thermistor bead sensor, signal-processing circuitry, and battery power source. The pill operated as a miniature pulsed oscillator, whose pulse repetition frequency was determined by response of the thermistor. Each pill was calibrated in units of 0.1°C between 34° and 40°C and recalibrated 12 hours prior to use. The pill was swallowed by the test diver, then an antenna positioned in the abdominal area to pick up signals from the pill. The antenna, in turn, was connected to the junction box and then to the meter readouts on the monitoring console. Separate 4-meter consoles were used in order to easily distinguish the pilot's data from the navigator's data. The meters read arm, back, thigh and core temperature directly in degrees centigrade.

c) Electrocardiogram (ECG). Electrocardiograms were obtained from each diver on all test runs. Two electrodes were positioned on the diver's chest and held in place by Stomaseal Adhesive Discs. The electrodes were from Dispos-El Disposable Electrode Kits manufactured by Becton Dickinson, Rutherford, New Jersey. The electrode leads were hard-wired via underwater connectors to the junction box and then to jacks which could be inserted into an oscillograph recorder to obtain a sample electrocardiogram. The record was analyzed for heart rate by use of a Burdick ECG Rule.

Figure 2 shows the four-meter temperature-monitoring console used to monitor each diver, the emplacement of the consoles at the physiological monitoring station, and the taking of heart rate readings by the Diving Medical Officer. Figure 3 is a sample sheet from the form used

Figure 2. Physiological Monitoring Equipment

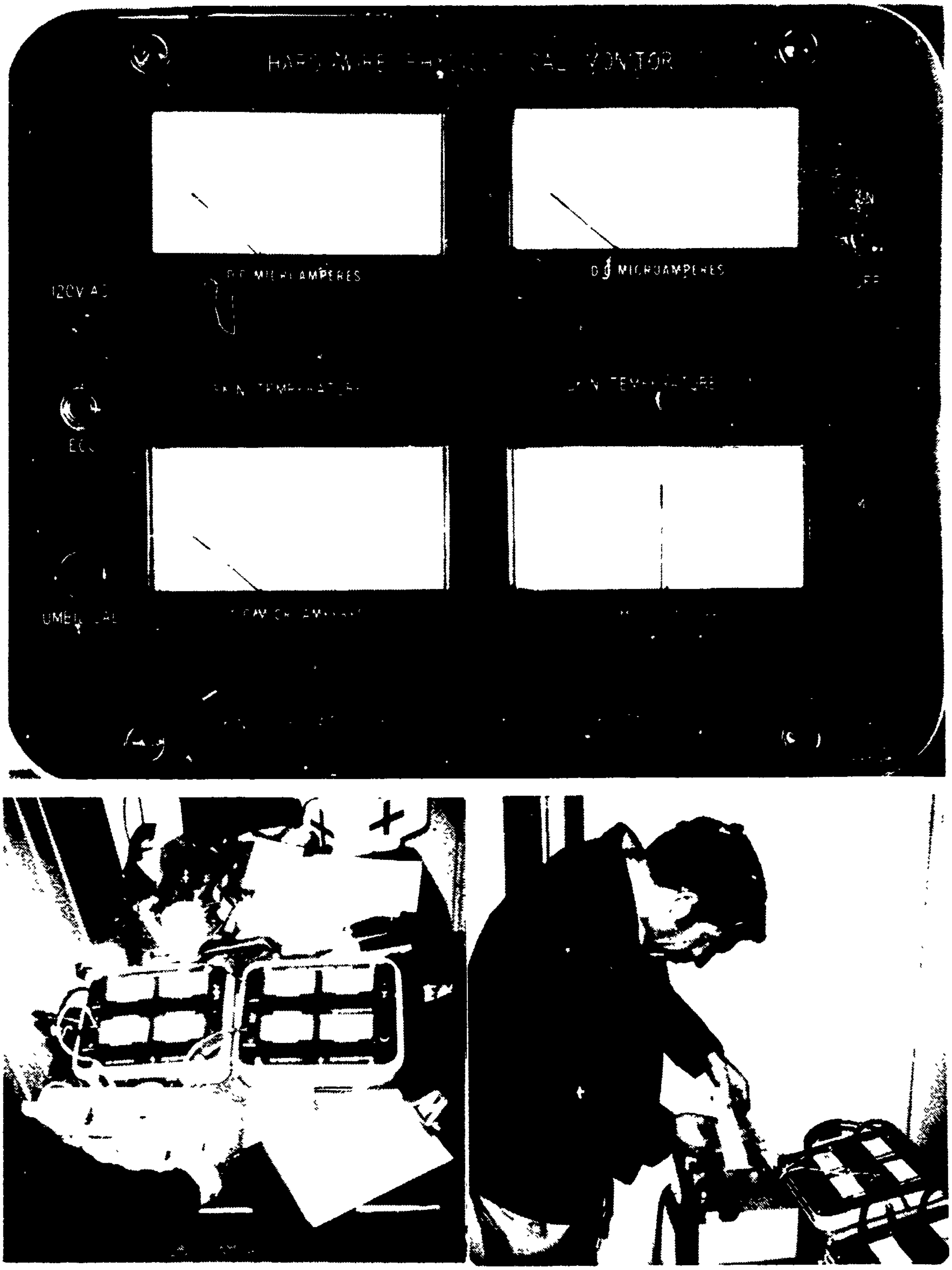


Figure 3. Physiological Data Recording Form

Pilot____________________ Date____________________

Navigator____________________ Run Category____________________

	PILOT DATA					NAVIGATOR DATA				
Time Min.	Core Temp.	Skin Temp.			HR	Core Temp.	Skin Temp.			HR
		Leg	Torso	Arm			Leg	Torso	Arm	
00										
10										
20										
30										
40										
50										
60										
70										
80										
90										
100										
110										
120										
130										
140										
150										
160										
170										
180										

to record physiological data.

2. Task performance monitoring

a) SDV control system simulator. A MK VII Mod O SDV was modified to work as a simulator for the in-water phases of the test scenario. The pilot's station consisted of a joystick control and a 3-section display console. In the center section of the console were a 0-50-foot round-dial depth gauge, and a round-dial compass repeater with indicator needle. The depth indicator was linked to the fore-aft movement of the joystick: pushing the joystick forward moved the depth indicator toward 50 feet, pulling the joystick aft moved the indicator toward zero. Rate of needle movement was a function of extent of joystick displacement so that the relationship between stick movement and needle movement was qualitatively comparable to actual operations of the MK VII SDV. The heading indicator moved clockwise around the compass rose in response to right displacement of the joystick, and counterclockwise in response to left displacement. As with depth, rate of needle movement around the display was a linear function of stick displacement. For both heading and depth control, stick displacement moved a sensor element over the length of an electrically resistant plate. Position of the sensor on the plate determined both direction and rate of movement of the appropriate indicator needle. The "center" position of the plate was scribed to create a break in the plate which was narrower than the sensor element. In this configuration, the pilot could not find and hold a stick position which would center the displays; he was required to continuously work the joystick in order to bring the depth and heading needles toward their prescribed values.

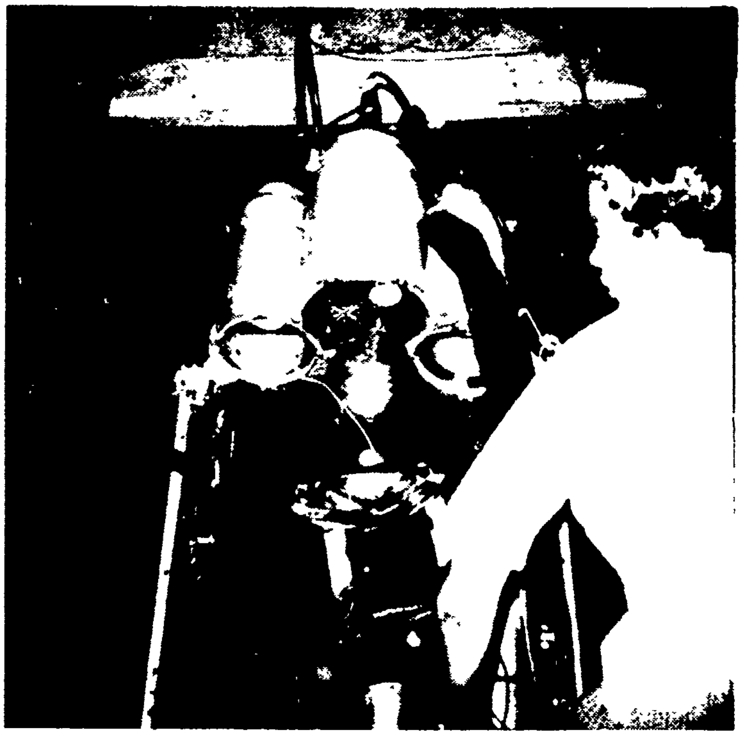
In the control and monitoring van, signals from the stick and from the heading and depth displays were recorded on magnetic tape (AMPEX FR-1300) and on an eight-channel chart paper recorder (Brush Ultralinear Oscillograph). Frequency and amplitude of stick movements fore/aft and left/right were recorded; deviation from prescribed heading and depth were recorded. Prescribed depth was 25 feet for all legs of the test scenario and so the zero reference for depth deviation could be fixed. Since heading changes were prescribed by the test scenario (3 legs per hour) and heading adjustments were ordered by the navigator on each leg, a re-centering mechanism for heading was provided for in the control and monitoring van.

b) Obstacle avoidance system display simulator. An obstacle avoidance system display simulator, manufactured by Applied Research Laboratory, University of Texas, was added to the MK VII SDV control system simulator. This display was essentially an oscilloscope on whose face targets could be made to appear via the signal-generation equipment in the control van. The pilot's display screen was approximately 3-inches high and 4-1/2-inches wide. Lines on the display face divided the area into four sectors relative to the SDV's center line: far left, center left, center right, far right; and into vertical sectors representing distances from the SDV. The outermost range ring could be set to represent 500, 200, 100 or 50 yards. Signals could be made to appear on the pilot's screen in a variety of sizes, shapes, levels of intensity, and locations as controlled by the signal generator. Once a target was inserted, it moved from its initial location toward the bottom of the display face at a rate of movement determined by the range scale selected. Also a function of range scale were signal flicker frequency, image size and time on the display. The signal movement was also affected by the SDV left/right stick movement such that if the stick was displaced right, the signal would be displaced left, as though the SDV were steering away from an obstacle in its path. For the tests reported here, the obstacle avoidance display was set at a 100-yard maximum range; therefore, the signal flicker frequency was 5 per second, time-on-scope was a maximum of 45 seconds, and rate of movement down the display face was 1.67 mm per second. The target shape selected was a rectangle, and a size and intensity combination was empirically determined during pre-tests to provide signals that were detected at approximately 90% probability. Targets were inserted at random times and in random sectors according to a schedule drawn up prior to each test series. The pilot's response was to press a button on the top of the joystick when he noted a target and then to make one of three responses depending on the target's sector. If the target was in the center left, he was to veer off sharply right then return to course; if the target was in the center right, he veered off left; if the target was in either extreme sector, he was to hold course. The pilot's responses were monitored in the control van, and records were kept of target misses, target acquisition time delay, and correctness of the maneuver response.

Figure 4 shows the pilot's work station in the SDV simulator. In the center console section are the simulated compass repeater and depth display. In the left section is the simulated obstacle avoidance system (OAS) display. Also shown is the OAS controller's console in the control and monitoring van. Figure 5 shows a sample sheet of the input schedule and response evaluation form used by the OAS controller.

c) Doppler navigation display simulator. An experimental display was developed which presented information about the SDV's position with reference to an intended track. This equipment consisted of two elements: a waterproof display mounted in the after compartment of the SDV simulator, and a control and monitoring console located in the control van. The control console was used to insert rates of movement in two directions, across track and along track, for each leg of the test scenario. The combination of these two rates of movement through time created a vector problem for the navigator to solve. The underwater unit displayed time-on-leg in minutes and tenths, yards across track, and yards along track, the latter two values being a straight-line function of the two rates programmed for the particular leg. On a waterproof response form, the navigator plotted the SDV's position with reference to intended track, and from the plotted xy coordinates he constructed a vector triangle. By measuring different aspects of the triangle he generated five

Figure 4. Pilot Work Station and OAS Simulator Control



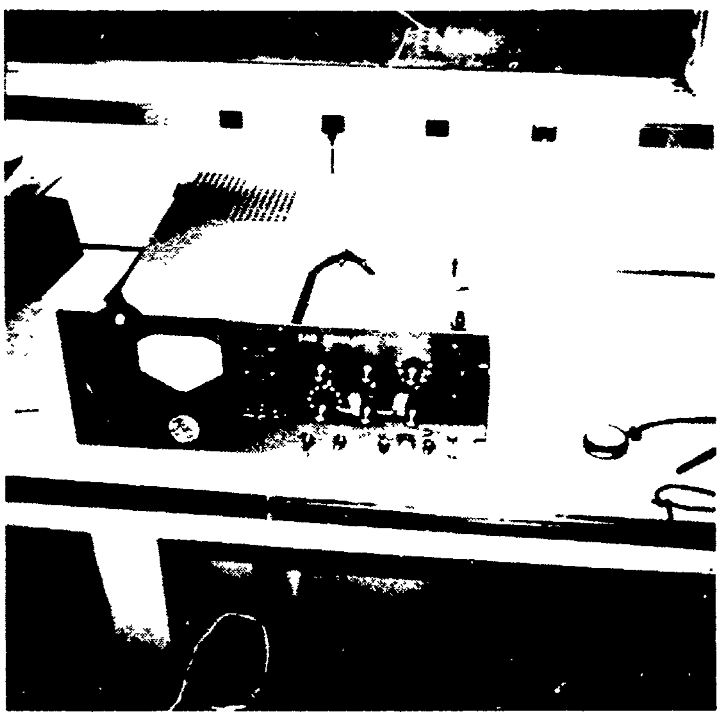


Figure 5
OAS Simulator Control Input Schedule and Response Data

Pilot________________________ Run Type___________

Date_________________________ Hour____of____Hours

Signal No.	On Time (2-58)	Quadrant (1-4)	Detection (yes/no)	Response Delay Time (1/100th min.)	Avoidance Maneuver (correct/incorrect)
1	02	Q3			
2	05	Q4			
3	16	Q1			
4	22	Q2			
5	26	Q4			
6	30	Q2			
7	35	Q2			
8	45	Q3			
9	51	Q1			
10	57	Q1			

values: SDV speed and course over the ground, current set and drift, and corrected SDV course which compensated for the effects of the current.

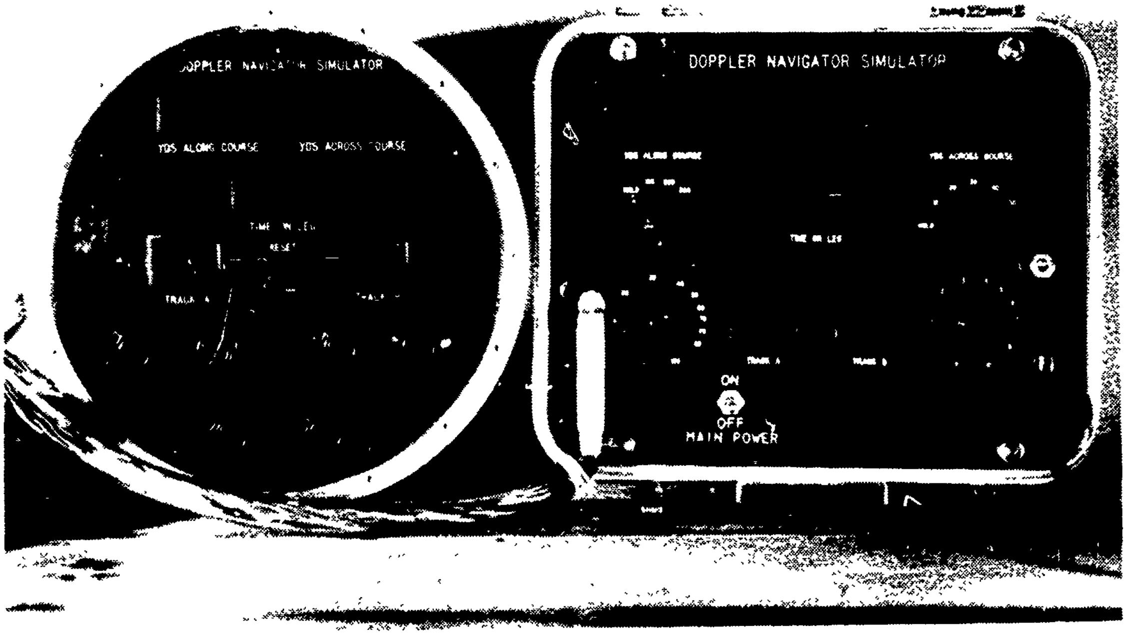
When the problem was solved and a corrected course determined, the navigator dialed a corrected course into his display which was repeated at the control console. Since the navigator made xy plots at 3rd, 6th and 9th minutes of the leg, his problem-solving time was the time he dialed in a corrected course, less 9 minutes. As each leg was of 20 minutes duration, the test navigator had a maximum of 11 minutes in which to do his work. The navigator task therefore provided both time and accuracy dimensions for scoring and evaluating problem-solving effectiveness.

A sample vector problem is illustrated in Appendix A.

Figure 6 illustrates the navigator's work station in the SDV simulator and the details of the simulation displays. The cylindrical unit was waterproof and was mounted in the after compartment of the SDV simulator. The rectangular unit was located in the control and monitoring van, and was used by the NAV controller to set in problem parameters for each leg. Figure 7 is a sample sheet of the NAV controller's schedule of along and across-track rates for the first nine legs of the test scenario.

d) Dynamometers. One- and two-hand dynamometers were used to test for effects of exposure on strength in those areas related to cable cutter and wire cutter use. The one-hand dynamometer was the Jamar Adjustable Dynamometer, manufactured by Marsh Instrument Company, Skokie, Illinois. This instrument registered the gripping force of the hand directly in pounds of force between zero and 200 pounds. The two-hand dynamometer was constructed by adapting an opposing handle to a torque wrench. The handles were 24 inches in length, and the angle between the two handles was 54 degrees. The torque wrench registered pounds of force between zero and 250 pounds. Figure 8 shows the two-hand and one-hand dynamometers.

Figure 6. Navigator Work Station and Doppler Navigation Simulation Equipment



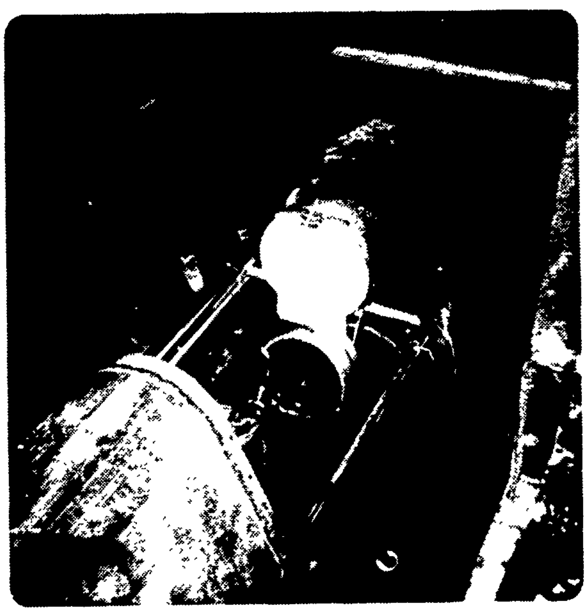


Figure 7
Doppler Simulator Data Entry Form

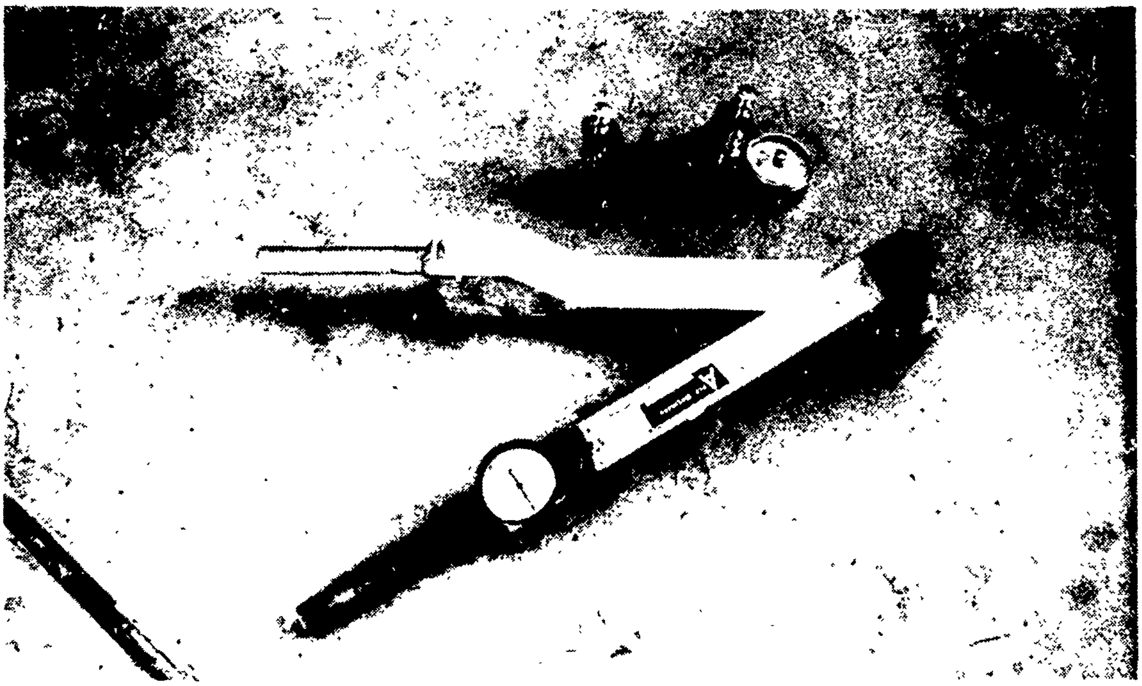
Navigator _______ _________ Hour______of______________

Run Type __________________

Date______________________ Problems______thru__________

Problem No.	Leg Number	SDV Course	Along Track Error Rate	Across Track Error Rate
Hour #1				
1-1	1	062°	170	R 33
1-2	2	178°	240	L 68
1-3	3	240°	180	L 57
Hour #2				
2-1	4	018°	140	R 31
2-2	5	320°	170	L 52
2-3	6	252°	250	R 63
Hour #3				
3-1	7	184°	150	R 70
3-2	8	006°	130	R 63
3-3	9	288°	110	L 65

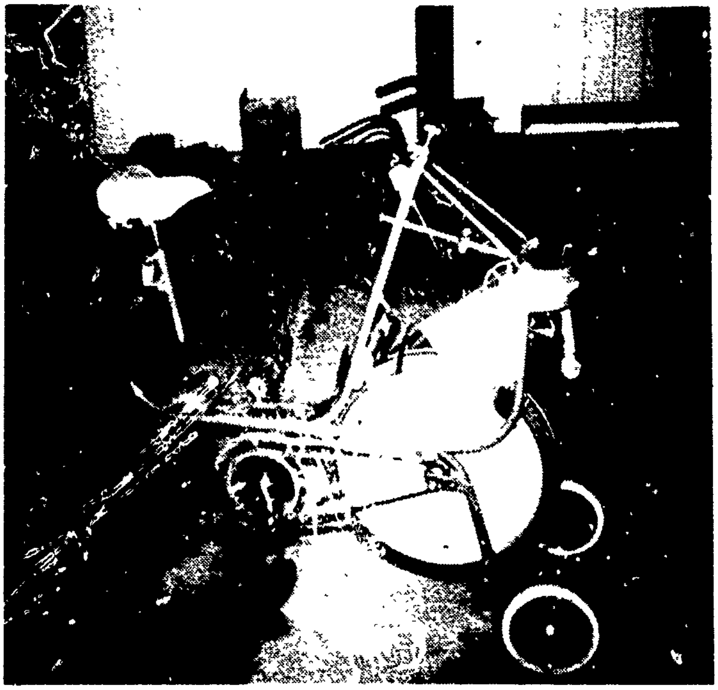
Figure 8. One and Two-Hand Dynamometers



e) Bicycle ergometer. The initial in-air scenario called for the men to run 1000 yards carrying approximately 40 pounds of equipment to an objective, then run back to the SDV pick-up location. This energy expenditure was eventually represented in the test scenario by a 5-minute pedaling of a bicycle ergometer at a fixed rate of 20 kilometers per hour, and under a fixed breaking load. The bicycle ergometer used was manufactured by Monark-Crescent AB of Varberg, Sweden, and is illustrated in Figure 9.

f) Map problem. An abstract map problem format was developed for inclusion in the in-air phase of the test scenario to tap arithmetic and problem-solving capabilities in air following a long (3-hour) cold water transit in an SDV. The map problem was in two parts: Part A dealt with the route from the delivery point to the objective, Part B from the objective to the rendezvous point. Both forms provided a 3-leg route, a north

Figure 9. Bicycle Ergometer



orientation, a scale of inches to the mile, and a rate of march for the terrain. The test diver was provided the abstract map, a pre-formatted response form, a rule, protractor, and pencil. He measured the lengths of the legs, used the scale factor to calculate miles per leg. He next used the rate of march to convert miles to travel time per leg, obtained a total time, and then an estimated ETA given a starting time. Finally, he recorded the compass orientation of each leg. Considering both Parts A and B, the abstract map problem required 6 rule measurements, 6 compass readings, 8 multiplications, 8 additions, 6 divisions and 2 subtractions. A sample map problem is presented in Appendix A.

g) Radio firing device. A simulated installation of a firing device was built into the test scenario as a test of procedures-following, and finger dexterity. The equipment used was the Radio Firing Device MK30 Mod O and the Radio Firing Device Control MK100 Mod O.

C. Test Scenario and Procedure

1. Pre-dive preparation

All personnel arrived at the test facility at 0630 to prepare for the test dive. Preparation was in two parts: readying the test divers, and setting-up the scenario control system. Preparation required approximately 1-1/2 hours.

a) Diver preparation. The test divers were fed a breakfast of pancakes or eggs prepared on site. Following breakfast, they swallowed the core temperature pill, which had been calibrated the previous evening. The men then undressed, and were weighed for purposes of assessing weight loss during the 6-hour exposure. Next, they were given a pre-dive medical check by the Diving Medical Officer. Finally, they were instrumented for skin temperature and ECG, and dressed.

b) Scenario control preparation. A folder had been previously prepared which contained all necessary control and recording forms for the particular dive pair in the particular test condition. These forms were distributed to the appropriate control station and needed materials accounted for. The following list of checks were made prior to each test dive:

- Main Test Building
  - water and air temperature check
  - rewarming method in operation
  - pilot slate with heading sequence
  - navigator underwater plotting boards and response forms, pencil, ruler, protractor
  - in-air scenario materials check--dynamometers, radio firing device, bicycle ergometer, map problem forms, pencils, protractors, rulers

.. physiological data forms at monitoring station

.. safety diver station check for communication monitoring/ air bottle

- Control and Monitoring Van

.. OAS controller schedule of targets and evaluation form, pencil, stop watch

.. NAV controller schedule of along and across-track rates per leg, pencil

.. SDV controller--heading, depth systems ON; heading of 1st leg dialed into centering device; Greenwich time signal ON

.. FM tape and chart-paper recording systems ON

c) Poolside checkout. When the test scenario control system check was completed and the divers had been readied, the divers walked from the diver instrumentation and dressing van to the main test building where they plugged into the physiological monitoring consoles. Any required adjustments were made until all variables were recording satisfactorily. Then, the divers entered the SDV simulator and the simulator was lowered into the pool a few feet while the divers adjusted their full-face masks and checked their communication equipment.

2. Test scenario

a) In-water test phase (Hours 1-3). The SDV simulator was lowered to the bottom of the pool, the pilot began working the stick to get the SDV simulator onto the initial heading and at a 25-foot depth. When he had achieved these values, he communicated "START" to the navigator who switched the NAV Display from "RESET" to "TRACK A" which started the timer and initiated accumulation of yards across and yards along-track according to the selected rates. The navigator monitored the timer and at the 3rd, 6th and 9th minutes, recorded the across-track and along-track values on the response form. Then he plotted these values on the plotting board and drew in the vectors constructing the vector triangle. Using the protractor and ruler, he then solved the vector triangle for SDV course and speed, current set and drift, and corrected SDV heading to adjust for the current. This new heading he communicated to the pilot and the pilot turned onto the adjusted heading. In the control and monitoring van the NAV Controller noted the time of the change in Track A on his console and told the SDV Simulator Technician to dial in a new centering heading. He then set in the across-track and along-track rates and the across-track direction of drift for the next leg. At the end of 20 minutes on the Track A leg, the navigator communicated the second heading to the pilot, reset the NAV Display to zero, and switched to Track B. Then he inserted the 3rd leg heading into Track A.

The OAS Controller, meanwhile, monitored the target signal on his display and set it up in the correct quadrant according to the schedule. At the indicated time for Target #1, he switched the target onto the pilot's display, recorded the acquisition time and evaluated the pilot's response. These general procedures continued through 3 hours, 3 legs per hour, and 22 obstacle signals distributed randomly throughout the 3-hour interval.

b) In-air test phase (Hour 4). The SDV simulator was winched out of the water and the divers were helped out of the simulator to the poolside work area. The divers removed their face masks and gloves, dried off with a towel, and drank 4 ounces of grape juice prior to starting the hour-long, in-air task sequence. First, the strength tests were administered and scores recorded. Second, both divers sat at a work table and completed the map problem. Problem completion times were taken with a stop watch and recorded. Third, the test divers, in turn, pedaled the bicycle ergometer for five minutes at a standard breaking load and at a prescribed rate. Next, the pair rigged the radio firing device and their task completion time was recorded. Finally, they repeated the bicycle ergometer work and the strength tests, then prepared to re-enter the SDV simulator. Figure 10 illustrates the data-recording form used during the in-air phase of the test scenario.

c) In-water test phase (Hours 5 and 6). Hours 5 and 6 were conducted in identical manner to hours 1-3. The navigator solved three vector problems per hour, while the pilot held depth, steered headings for legs 10-15, and scanned the OAS display for obstacles 23-38.

d) Rewarm phase (Hour 7). Immediately upon completion of the sixth hour of the test scenario, the test divers got into the hot-water rewarming tank or the hot-air rewarming van located adjacent to the main test building. The cables connecting the physiological sensors to the display consoles extended the distance to these facilities so that core temperatures could be monitored during the rewarm process. While rewarming in the hot water bath, the divers gradually removed their wet suits as they accommodated to the 40°C (104°F) temperature. In the hot-air rewarming van, the procedure was to quickly remove the wet suit, dry off, and get into light cotton sweat shirt and pants, and wrap in a wool blanket. Rewarm phase was concluded as each diver's core temperature became 37.0°C (98.6°F).

3. Post-test operations. As the divers were rewarming, data from the navigator's response forms were recorded by the NAV Controller. The navigator's plotting boards and response forms were scrubbed and re-labeled for the next day's run. When the rewarm phase was completed, the physiological data sheets were added to the navigator response forms, OAS evaluation forms, and in-air scenario form and placed in an envelope, appropriately labeled to identify the test divers, the temperature conditions of the dive, and the rewarm procedure. The test divers were weighed to determine weight loss associated with the conditions of the test scenario, fed a light meal, and released. Finally, two radiosonde pills were calibrated for use the next morning.

Figure 11 presents an overview of the tasks performed in the context of the test scenario.

Figure 10. In-Air Scenario Data-Recording Form

Run Type ____ Duration ____ Date ____	Two-Hand Compression	Hand-Grip Strength		Map Problem Time	Bicycle Ergometer			RFD Time	Bicycle Ergometer			Two-Hand Compression	Hand-Grip Strength	
		Right	Left		Km Start	Km Fin.	Km Diff.		Km Start	Km Fin.	Km Diff.		Right	Left
Operator														
Navigator														

Figure 11
Overview of Tasks and Test Scenario

<table>
<tr><th></th><th>Hours 1, 2 and 3
In-Water</th><th>Hour 4
In-Air</th><th>Hours 5 and 6
In-Water</th><th>Hour 7
Rewarm Procedure</th></tr>
<tr><td>Pilot Tasks</td><td>Hold prescribed depth
Hold headings #1-9 in sequence
Adjust each heading in response to navigator instructions
Scan obstacle avoidance display for occurrence of targets #1-22
Press button indicating detection and perform correct avoidance maneuver</td><td rowspan="2">2-hand compression test
Hand grip strength tests
Map problem
Bicycle ergometer (run to objective)
Rig the firing device
Bicycle ergometer (return run)
Repeat strength tests</td><td>Hold prescribed depth
Hold headings #10-15 in sequence
Adjust each heading in response to navigator instructions
Scan obstacle avoidance display for occurrence of targets #23-38
Press button indicating detection and perform correct avoidance maneuver</td><td rowspan="2">Run #1
Hot Water at 40°C
Run #2
Hot Air at 38°C</td></tr>
<tr><td>Navigator Tasks</td><td>Plot SDV position at 3rd, 6th and 9th minutes of each leg
Draw SDV vector and current vector
Calculate SDV speed and course, current speed and direction, and adjusted heading for SDV
Communicate adjusted heading to pilot</td><td>Plot SDV position at 3rd, 6th and 9th minutes of each leg
Draw SDV vector and current vector
Calculate SDV speed and course, current speed and direction, and adjusted heading for SDV
Communicate adjusted heading to pilot</td></tr>
</table>

III. RESULTS

A. Physiological Effects

Each test diver made two runs through the test scenario under each of two exposure conditions: a cold condition where water and air temperatures were 4.5°C (40°F) and 10°C (50°F) respectively, and a control condition where these temperatures were 15.5°C (60°F) and 20°C (68°F). The physiological data from the two runs were averaged for each test diver and these values used to represent the skin temperature, core temperature, heart rate and weight loss for the diver for the particular condition. Individual data are presented in Appendix B, Basic Data Tables; this section presents summary results based on the means of the individual data.

Since each diver served as his own control for comparing physiological and performance response differences between the two exposure conditions, the statistical test of significance of difference between means used throughout this report was the t-test for matched pairs as described by Edwards (1954).

1. Skin temperatures. Skin surface temperatures were recorded from the upper arm, medial thigh and mid-back locations at 10-minute intervals throughout the test scenario. These data were averaged per hour to yield a mean hourly skin temperature estimate for each of the three locations. Figures 12, 13 and 14 show the mean hourly skin temperatures at these sites for the cold vs the control exposure conditions. Generally, these figures show skin temperatures declining during the 3-hour water exposure, recovering to some extent during the 4th hour's in-air work period, then declining again during the 5th and 6th hours in the water. At all points of comparison, the skin temperature means are significantly different between the cold and the control exposure conditions. The

Figure 12

MEAN HOURLY SKIN TEMPERATURE: UPPER ARM

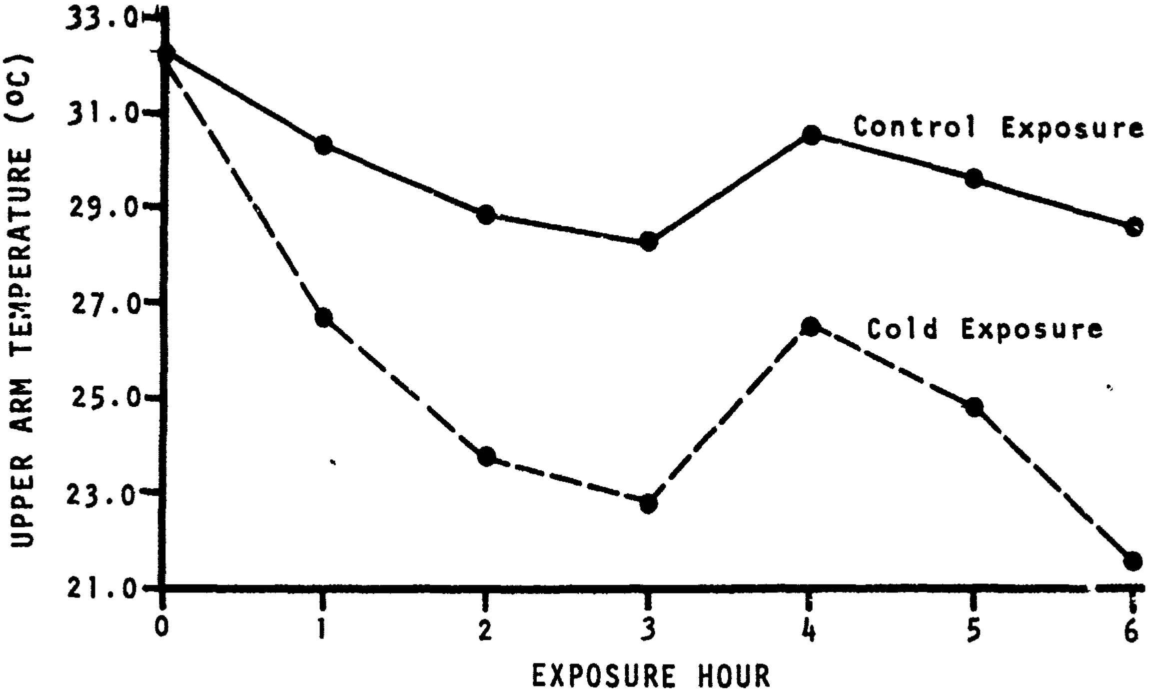


Figure 13

MEAN HOURLY SKIN TEMPERATURE: MEDIAL THIGH

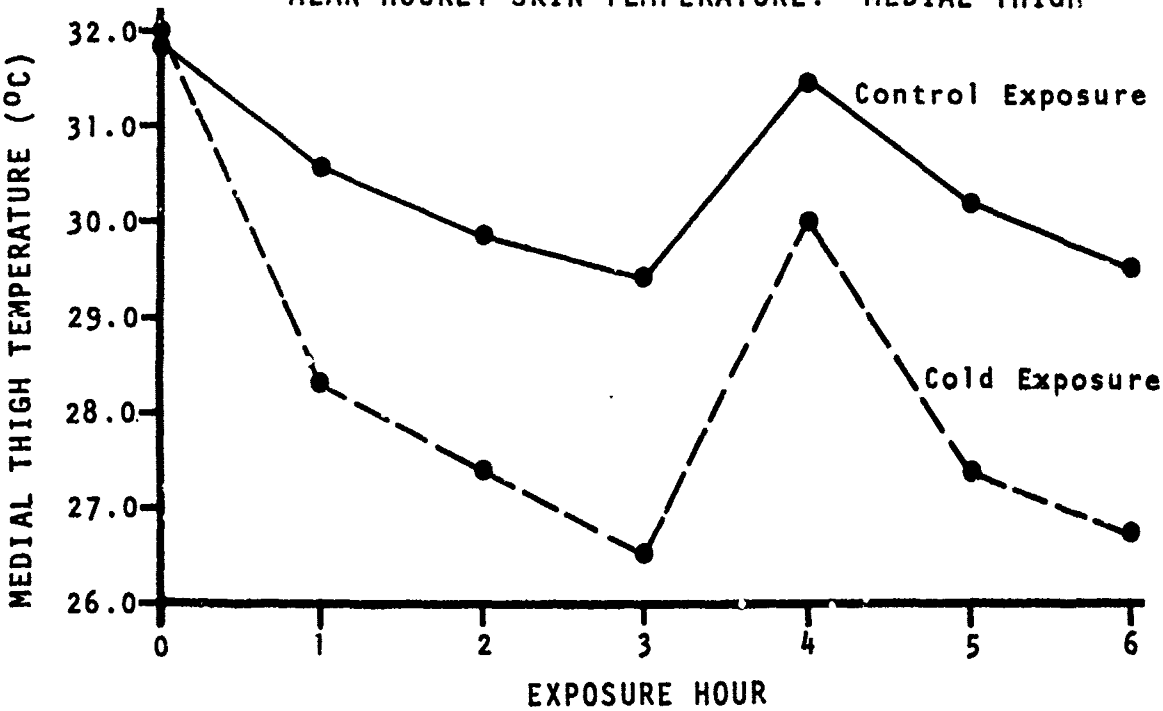
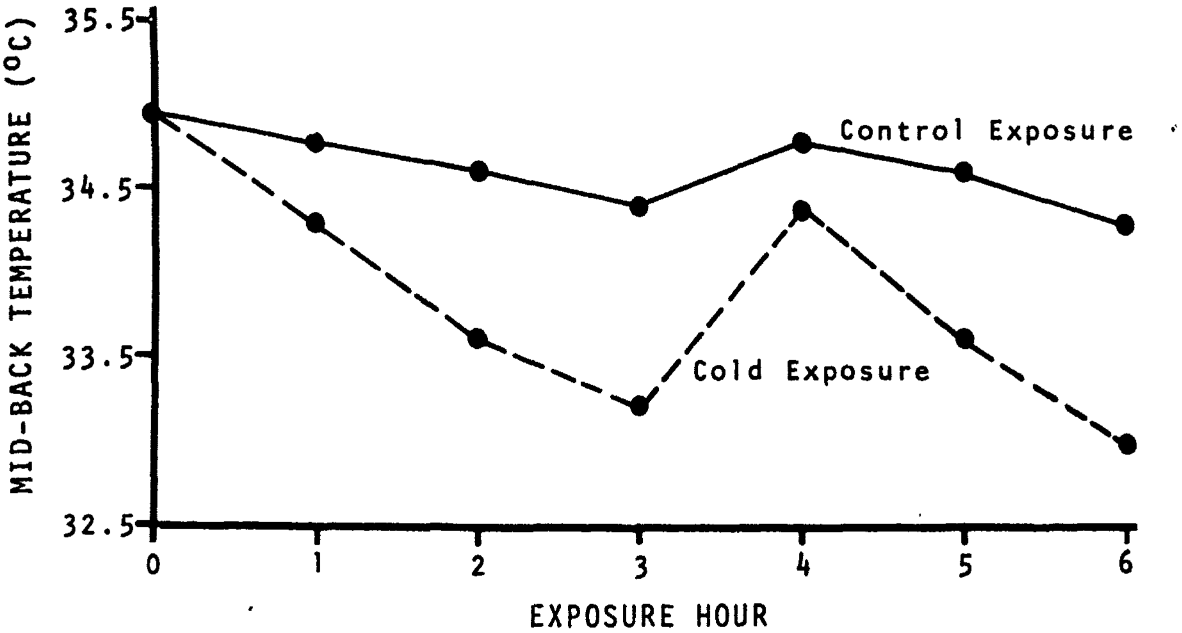


Figure 14

MEAN HOURLY SKIN TEMPERATURE:MID-BACK



upper arm location shows the greatest differences; the medial thigh location is next most affected; and the mid-back temperatures least affected by the differences between the cold vs the control exposure conditions. Given approximately equal initial temperature readings, the cold condition curves progressively depart from the control condition curves throughout the 6-hour exposure. Average differences in mean temperature readings were 5.1° C for the upper arm, 2.5° C for the medial thigh and 0.9° C for the mid-back.

2. Core temperature during exposure phases. Figure 15 shows core temperature profiles averaged over the eight test divers for the control vs the cold exposure conditions. The profiles show the early rise in core temperature from initial values, then a gradual decline for the remainder of the 3-hour water phase. At water exit, core temperature suffered a steep decline, achieving minimum values within 5-10 minutes of the water exit. This fall is assumed to be due to cold peripheral blood flowing back to the body core as a consequence of the arm and leg movements involved in exiting

the SDV simulator and performing the strength tests. Core temperature rose during the remainder of the in-air phase, reflecting the heat generated by the rather strenuous periods of physical exercise on the bicycle ergometer. Upon re-entering the water, core temperature fell again during the final 2-hour water phase of the test scenario. Figure 15 shows a consistent difference in core temperature as a consequence of the conditions of exposure, beginning with the second hour. For the first hour and a half, however, core temperatures were not differentially affected by the 11.1° C (20° F) difference in water temperature.

Table 3 is a summary of the core temperature values and changes which occurred during the exposure phases of the test scenario for the cold vs control exposure conditions. The average overall fall in core temperature was 0.8° C (1.4° F) for the cold exposure and 0.5° C (0.9° F) for the control. Average initial core temperatures were approximately equal (37.2° C vs 37.3° C), becoming progressively more disparate toward the end of the 6-hour exposure interval where average core temperatures were 36.7° C for the control condition and 36.5° C for the cold. Lowest points in the core temperature profiles were 36.3° C for the control and 36.2° C for the cold exposure condition. These low points occurred within 5-10 minutes of water exit following the first three hours in the water.

3. Core temperature during rewarm phase. Previous research with wet-suited divers in 6-hour, cold-water exposures (Vaughan and Swider, 1972) has shown that post-dive fall in core temperature during rewarming was a function of time of exposure to a given water temperature. Average post-dive fall was 0.1°C (0.2°F), 0.3°C (0.5°F) and 0.4°C (0.7°F) following 4-, 5- and 6-hour exposures to 6°C (43°F) water. These values occurred for a rewarm method of full immersion in 40°C (104°F) water bath. The dive profile for the present study was not a continuous cold water exposure so that direct comparison cannot be made with the study results referenced. However, it was anticipated that core temperature fall during rewarm would

Figure 15

MEAN CORE TEMPERATURE PROFILES DURING SIX-HOUR EXPOSURE PHASES

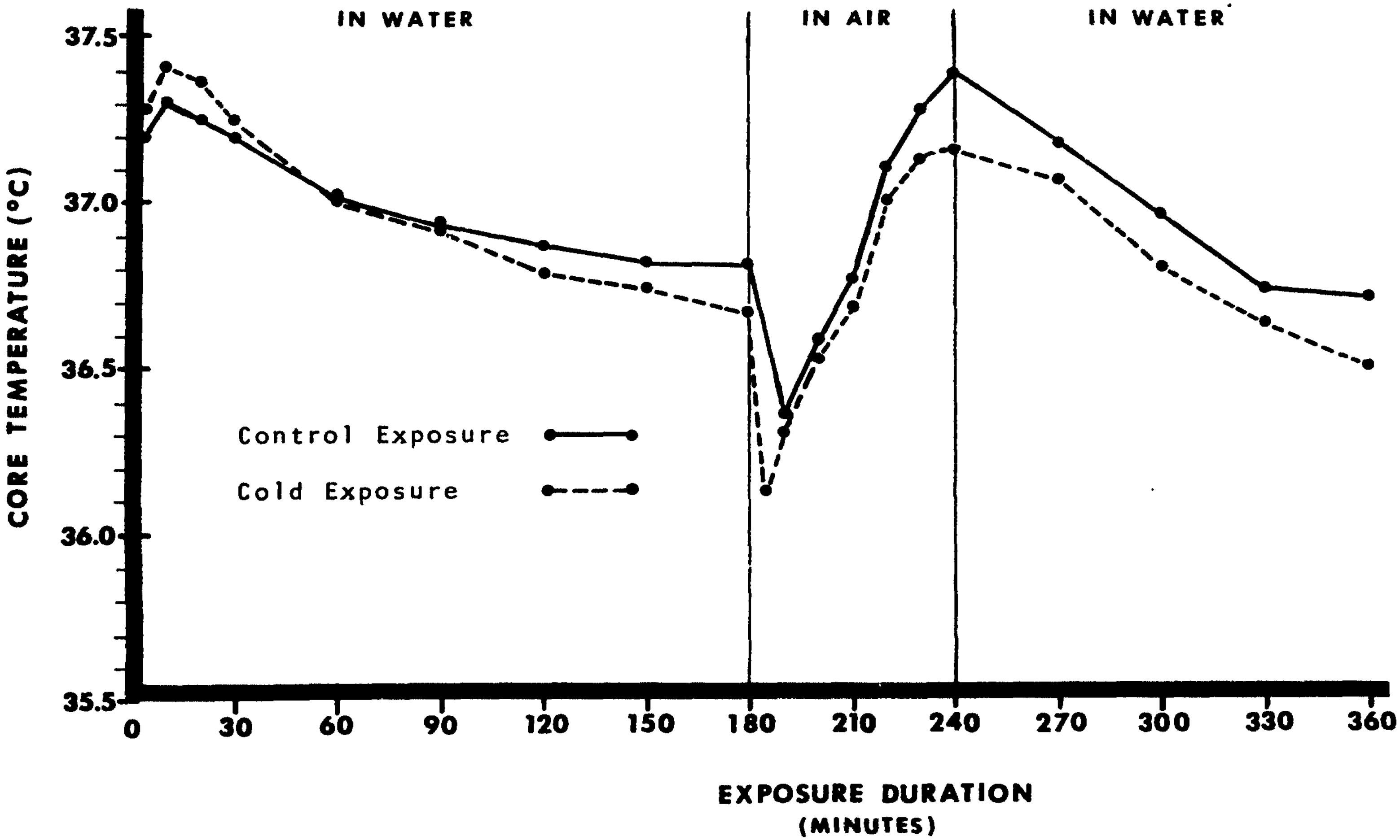


Table 3. Summary of Mean Core Temperature Changes During Exposure Phases

Exposure Phase	Mean Core Temperature Values	60°F. Water 68°F. Air	40°F. Water 50°F. Air
In-Water Hours 1-3	Core temperature at time 000 minutes	37.2° C	37.3° C
	Core temperature at time 180 minutes	36.8° C	36.7° C
	Loss during hours 1-3	0.4° C	0.6° C
In-Air Hour 4	Core temperature minimum	36.3° C	36.2° C
	Loss during in-air phase	0.5° C	0.5° C
In-Water Hours 5-6	Core temperature at time 240 minutes	37.4° C	37.2° C
	Core temperature at time 360 minutes	36.7°C	36.5° C
	Loss during hours 5-6	0.7° C	0.7° C
	Overall loss 000-360 min	0.5° C	0.8° C

be greater following the cold exposure than for the control exposure conditions. Since each of the eight test divers had rewarmed in hot water following both the cold exposure and the control exposure, the effect of prior exposure differences on the rewarming profile could be directly compared.

Since ideal rewarming facilities are not commonplace in areas where divers could be expected to be rewarming following a long, cold water exposure, a more conventional rewarming method was tested against the ideal. Each of the eight test divers rewarmed in the ideal hot-water bath method and in a conventional method following a 6-hour cold exposure. The conventional method consisted of getting the diver into a pre-heated room (air temperature of approximately 38°C (100°F), removing the wet suit, drying off with a towel, dressing in a light cotton sweat-suit and wrapping in a wool blanket. It was expected that the effect of the conventional rewarming method would be a greater core-temperature fall, and a longer period of recovery to normal core temperature in contrast to the hot-water immersion method.

Table 4 presents a summary of the mean core temperature changes during rewarm. Part A of the table compares the effects of differences in exposure conditions of the dive on post-dive fall and recovery of core temperature. The main consequence of the exposure differences was in extent of core temperature fall during rewarm. Following the control exposure condition, post-dive fall in core temperature was 0.3°C (0.5°F); and following the cold exposure condition, fall was 0.5°C (0.9°F). Recovery time, however, was identical. Given approximately 30 minutes in the hot water bath, average core temperature had returned to normal, regardless of the differences in the exposure conditions of the dive.

Part B of Table 4 presents the effects of hot-air vs hot-water rewarm methods following an identical 6-hour exposure: 3 hours at 4.5° C water, 1 hour at 10° C air, and 2 hours at 4.5° C water. No differences in extent of core temperature fall occurred as a function of rewarm method. Average fall was 0.5°C (0.9°F) for the hot water rewarm and 0.5°C (0.9°F) for the

Table 4

Summary of Mean Core Temperature Changes
During Rewarming Phase

A. Effects of Exposure Condition on Core Temperature Recovery During Rewarming in Hot Water

	Control Exposure	Cold Exposure
Core temperature at water exit	36.7° C	36.6° C
Core temperature minimum	36.4° C	36.1° C
Loss during rewarm	0.3° C	0.5° C
Time to recovery to 37°C	31 Min.	31 Min.

B. Effects of Hot Water vs Hot Air Rewarm Method Following 6-Hour Cold Exposure

	Hot Water Rewarm	Hot Air Rewarm
Core temperature at water exit	36.6° C	36.5° C
Core temperature minimum	36.1° C	36.0° C
Loss during rewarm	0.5° C	0.5° C
Time to recovery to 37°C	28 Min.	52 Min.

hot-air method. Recovery time, however, was significantly affected. Recovery of core temperature to normal level required 28 minutes in the hot-water bath and 52 minutes in the hot-air van.

Figures 16 and 17 graphically portray the summary data of Table 4.

4. Heart rate and weight loss. Accompanying the decline in skin and core temperatures over the 6-hour exposures are processes involved in the production of body heat to compensate, in part, for heat lost to the cold water. Two indices of the physiological cost of cold exposure are heart rate and weight loss; heart rate reflecting oxygen uptake and weight loss reflecting metabolic activity. Heart rate and weight loss were expected to be higher in the cold than in the control exposures. Figure 18 shows average hourly heart rate for the eight test divers during the cold and the control exposure conditions in relation to their mean resting level of 57 bpm. Both curves show high heart-rate levels upon water entry, then a decrease as a function of immersion and body cooling. In every hour, however, the heart rates associated with the 4.5°C (40°F) water were significantly higher than those for the 15.5°C (60°F) water exposures.

Average diver weight loss for the control exposure was 2.0 pounds; 2.7 pounds during the cold exposure.

B. Performance Effects

Performance effects of the exposure conditions were examined in two main categories: the in-water tasks, and the in-air tasks. In-water tasks were further subdivided into pilot tasks and navigator tasks. Assessment of pilot task performance will be limited in this report to the vigilance monitoring aspects of the complete subset since the heading, depth, and stick movement data are on FM tape and yet to be analyzed. Pilot task areas assessed included signal detection percentage, signal acquisition time, and choice reaction. The navigator tasks included solving three navigation

Figure 16

MEAN CORE TEMPERATURE RECOVERY PROFILES
DURING HOT WATER REWARM FOR TWO
EXPOSURE CONDITIONS

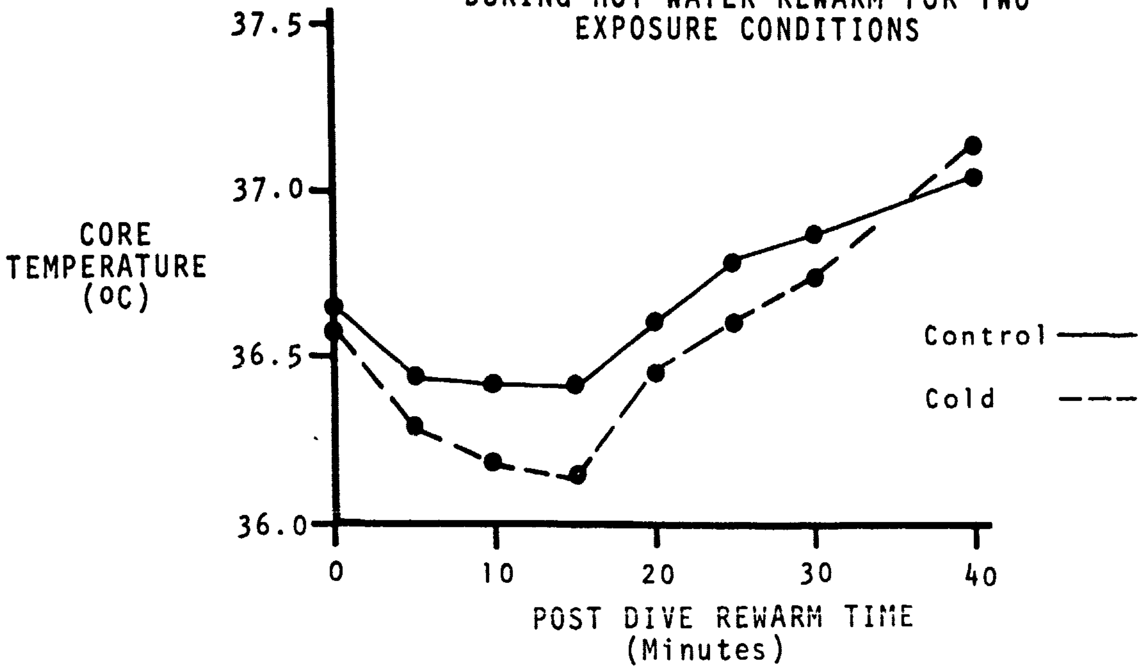


Figure 17

MEAN CORE TEMPERATURE RECOVERY PROFILES
FOR HOT WATER vs HOT AIR REWARM
FOLLOWING 6-HOUR COLD EXPOSURE

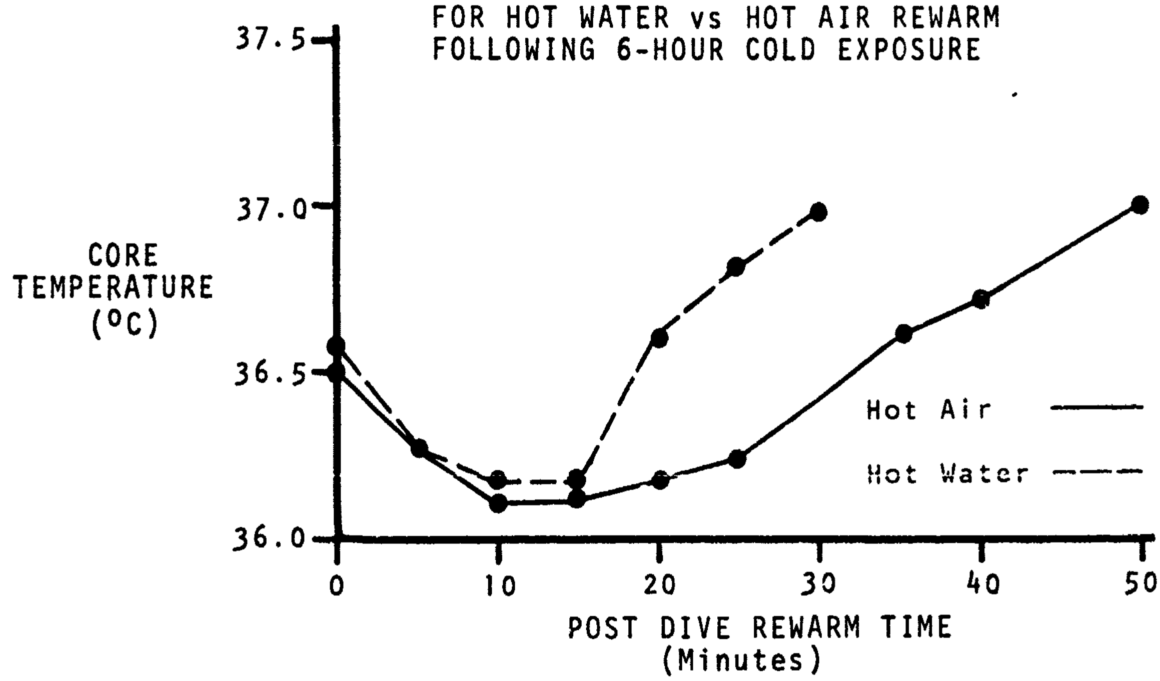
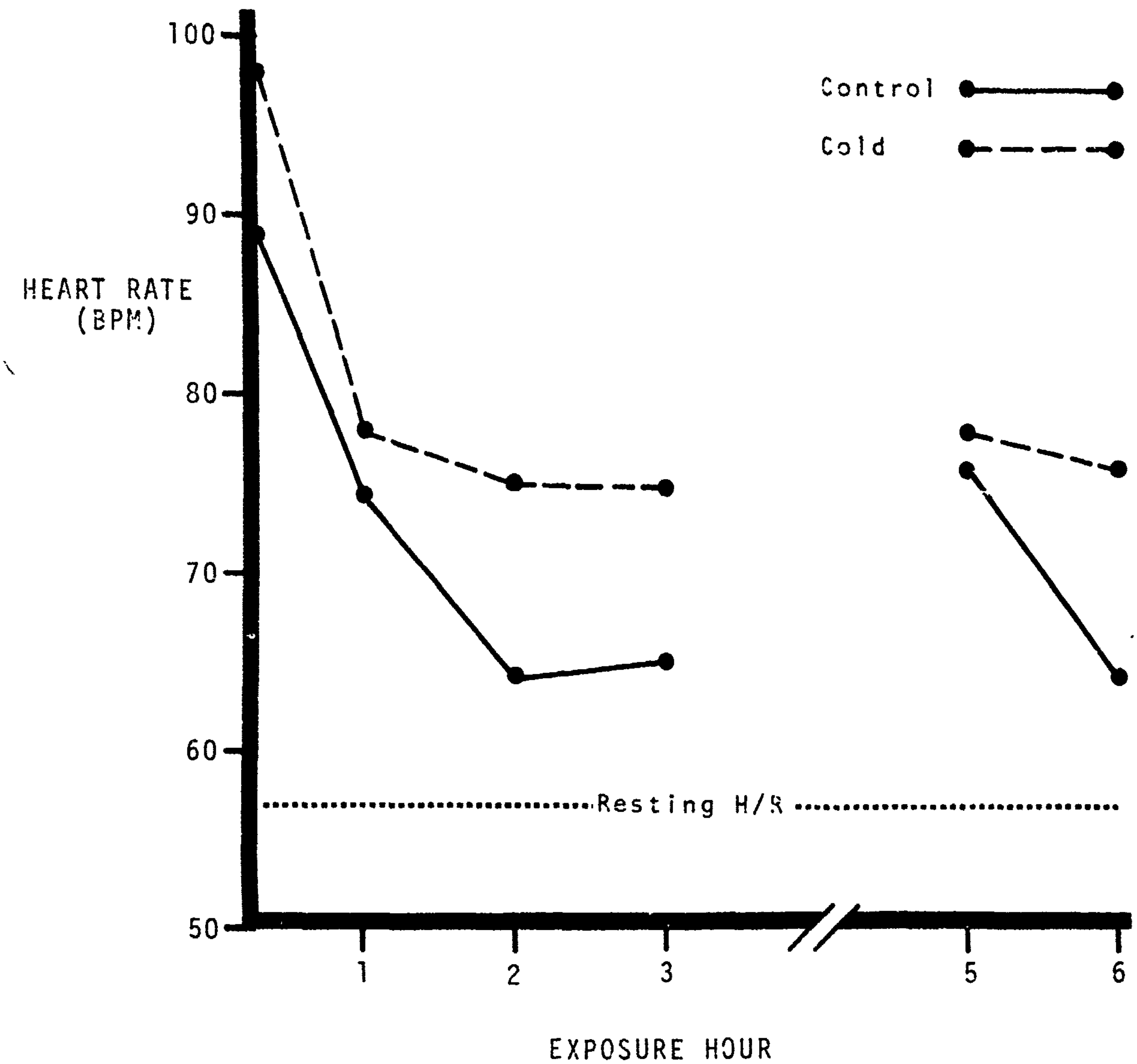


Figure 18
MEAN HOURLY HEART RATE



problems per hour where each problem involved five solution components. Performance was assessed in terms of per-hour accuracy and time to solution. In-air task performance was measured in terms of force production, and navigation problem-solving time and accuracy.

Data were analyzed in two stages. The first analysis focused on potential differences in performance effectiveness as a consequence of the two exposure conditions: control vs cold. In all task areas it was hypothesized that the colder exposure condition would result in poorer performance: slower response times, decreased accuracy, less strength, etc. The test of significance used to evaluate mean differences was the t-test for matched pairs and since the hypotheses were unidirectional, a one-tailed test was used to establish probability values. In those instances where differences between means were not significant according to the statistical test the performance data were combined.

The second analyses evaluated mean differences in performance as a function of exposure time. Hour-to-hour means were evaluated by the same statistical test used to assess differences in exposure condition. Figures presenting the evaluated results, therefore, show different values for cold vs control condition only where those differences were significant. Tables of significance tests conducted are presented in Appendix C.

1. In-water tasks

a) Vigilance monitoring and response. Target signals representing obstacles were presented on the pilot's OAS display at randomly determined times during each hour of the in-water phases of the test scenario. Number of targets presented per hour were 6, 8, 8, 7 and 9 respectively for hours 1, 2, 3, 5 and 6. Performance was assessed in three dimensions. Detection percentage was defined as the ratio of the number of signals detected, to the number presented. Detection latency was the elapsed time between signal onset and an indication by the pilot that he had detected its presence.

Choice-reaction accuracy was the percentage of correct responses to those targets detected.

Figure 19 shows that water temperature differences did not significantly affect the percentage of targets detected except in the first hour of exposure. Target detection percentage generally degraded from 100% to 96.9% to 86.6% during the first three hours of exposure; recovered to 89.9% during the fifth hour following the in-air phase and fell to 79.1% during the sixth hour. Performance deterioration appeared to be related to temporal effects of a long test scenario, but, except in the first hour, not specifically sensitive to water temperature differences.

Time delay in the acquisition of signals shows a similar pattern of performance effects. Figure 20 again indicates the influence of the 40°F water during the first hour. Significantly longer acquisition times were associated with the 40°F vs 60°F water temperatures. No differences were found in detection latency during the second hour, but occurred again in the third. Following the in-air work phase, no differences were found in detection latency during the fifth and sixth hours as a function of water temperature differences. As with detection percentage, hour-to-hour differences were highly significant, suggesting a set of temporal effects independent of water temperature differences.

Choice reaction accuracy offers an identical picture of performance degradation. Water temperature differences appeared to be a factor <u>only</u> during the initial exposure hour. Hour-to-hour differences trend in a gradually deteriorating progression, although c / the difference between hours 5 and 6 was statistically significant. Figure 21 presents the evaluated data regarding this dimension of vigilance monitoring and response.

<u>b) Navigation problem-solving</u>. In each hour, the navigator was presented with three navigation vector problems to solve. Each problem had five components to its solution, providing fifteen scorable responses per

Figure 19

DETECTION PERCENTAGE

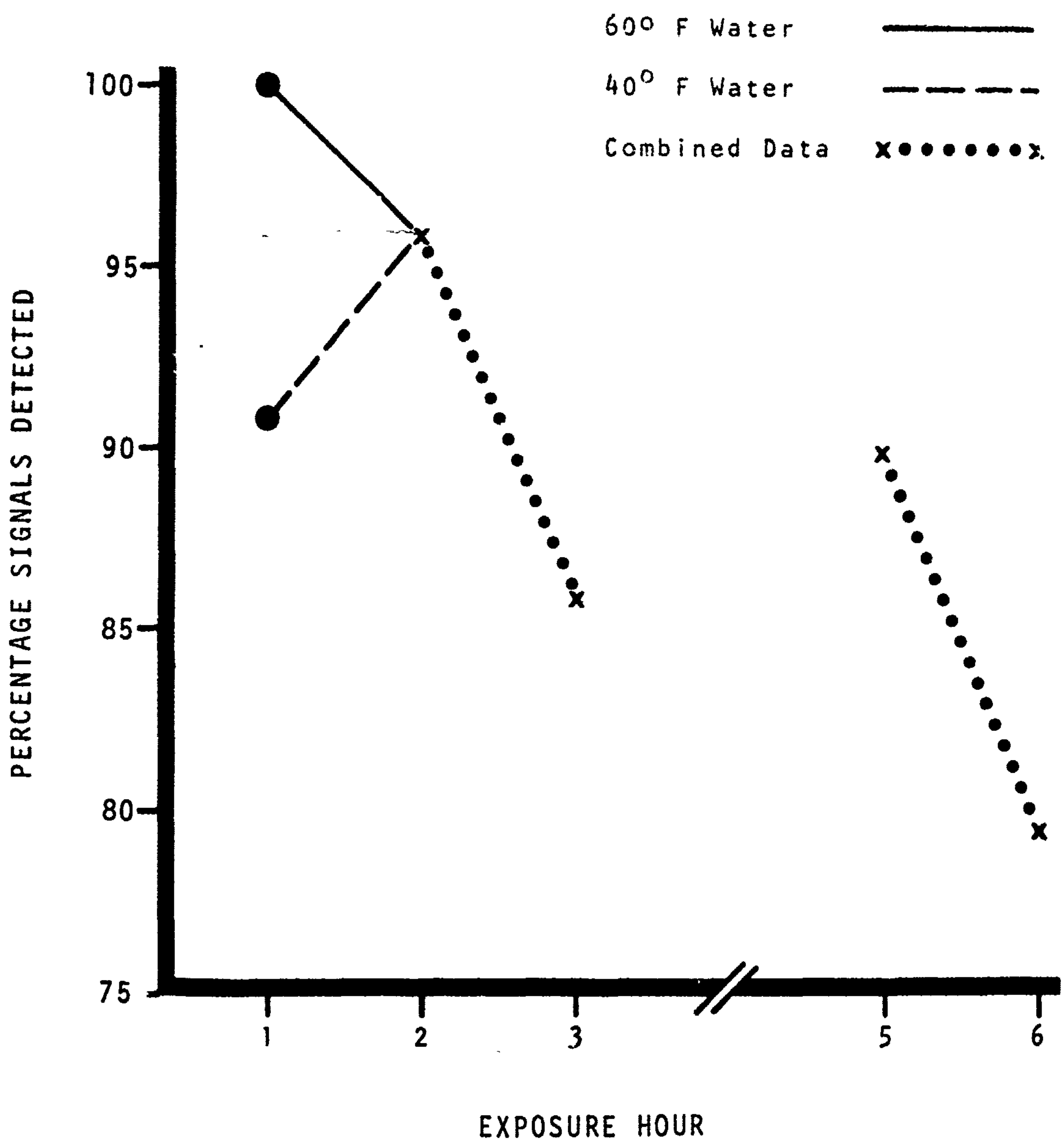


Figure 20

DETECTION LATENCY

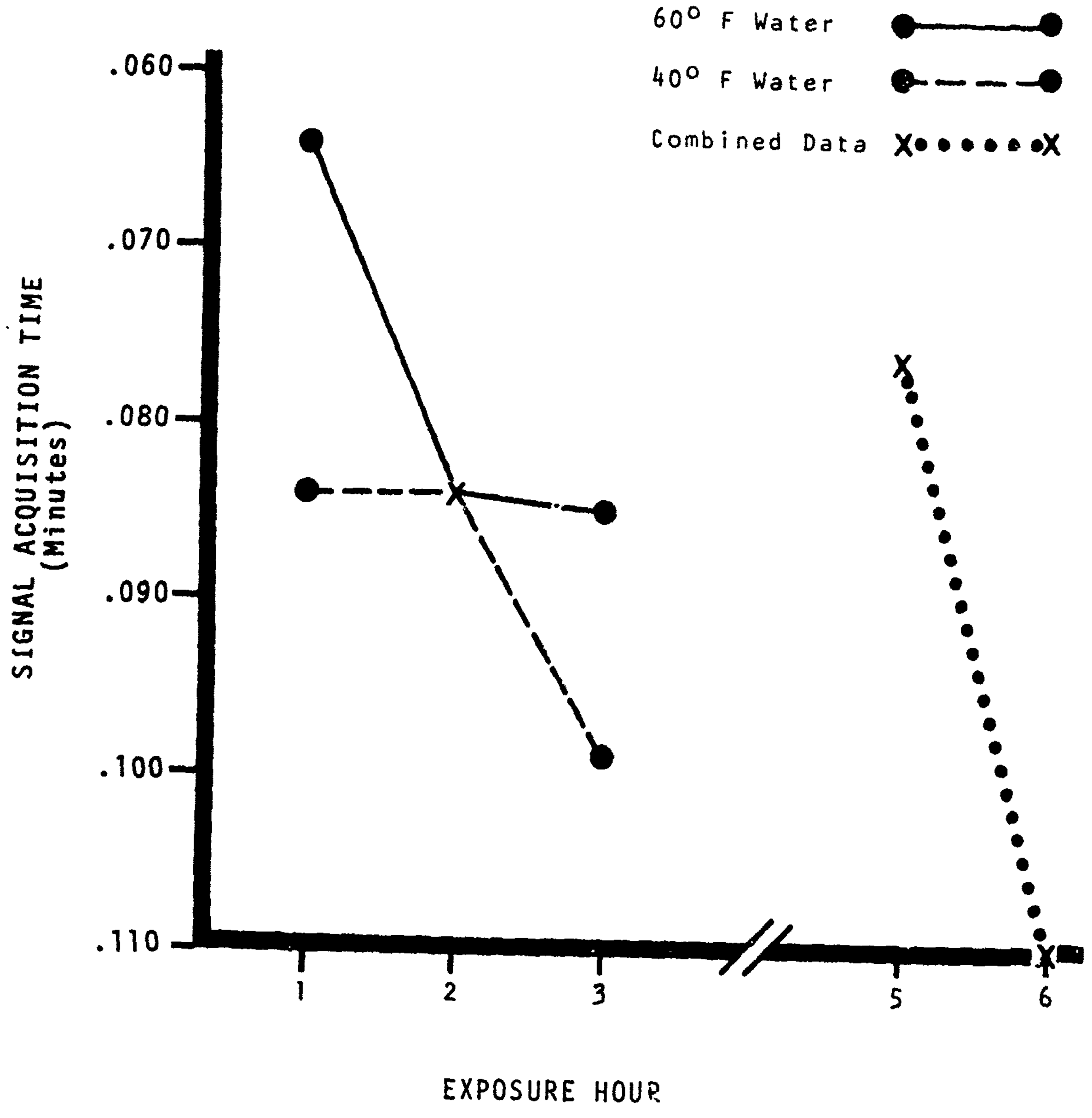
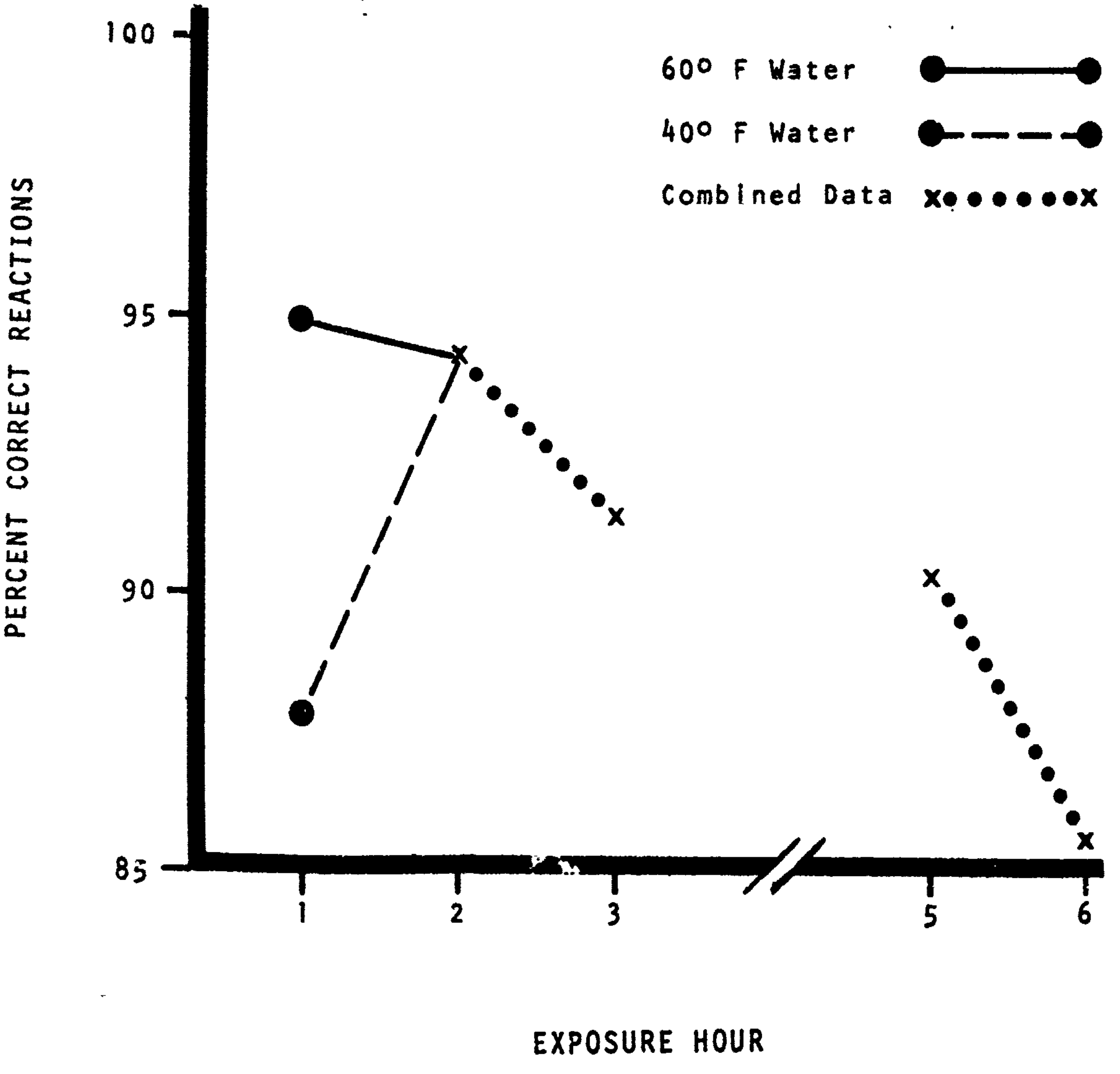


Figure 21

CHOICE REACTION ACCURACY



hour. Percentage of these fifteen solution components correct was used as a measure of problem-solving accuracy per hour.

Problem-solving time was defined as the interval between the ninth minute on the leg and the time the final element of the solution was recorded. Since the elapsed time indicator in the navigator's console repeated on the NAV Controller's console, the controller could record problem-solving time for each leg. In addition to accuracy and time, a third dimension potentially diagnostic of performance deterioration, problem omission, was recorded.

Problem-solving accuracy (Figure 22) was significantly affected by differences in water temperature during the first hour of the test scenario. In the 60°F water, average accuracy was 69.2% while only 54.2% in the 40°F water. Water temperature differences did not significantly affect problem-solving accuracy during the second and third hours, however. Water temperature appeared as a significant influence in problem-solving accuracy again in the fifth and sixth hours of the test scenario. Hour-to-hour differences in accuracy were significant except for the fifth-sixth hours in 40°F water.

Problem-solving time also reflected a significant effect of water temperature on performance during the first hour of exposure. Figure 23 shows solution time following a gradual decrease to an asymptotic level for the 60°F water; a depressed first hour in the 40°F water condition, then a recovery during the second and third hours. The fifth hour exposure showed no differences in problem-solving time as a function of water temperature; in the sixth hour, problem-solving time remained constant for the 60°F water condition, but a significant increase was associated with performance in the 40°F water.

The most discriminating measure of performance in terms of sensitivity to cold conditions was <u>number of omissions</u>. In the later hours of the exposure scenario (hours 3 and 6) six of the eight test divers omitted solution components of at least one problem. No omissions occurred in the 60°F water condition.

Figure 22
NAVIGATION PROBLEM - SOLVING ACCURACY

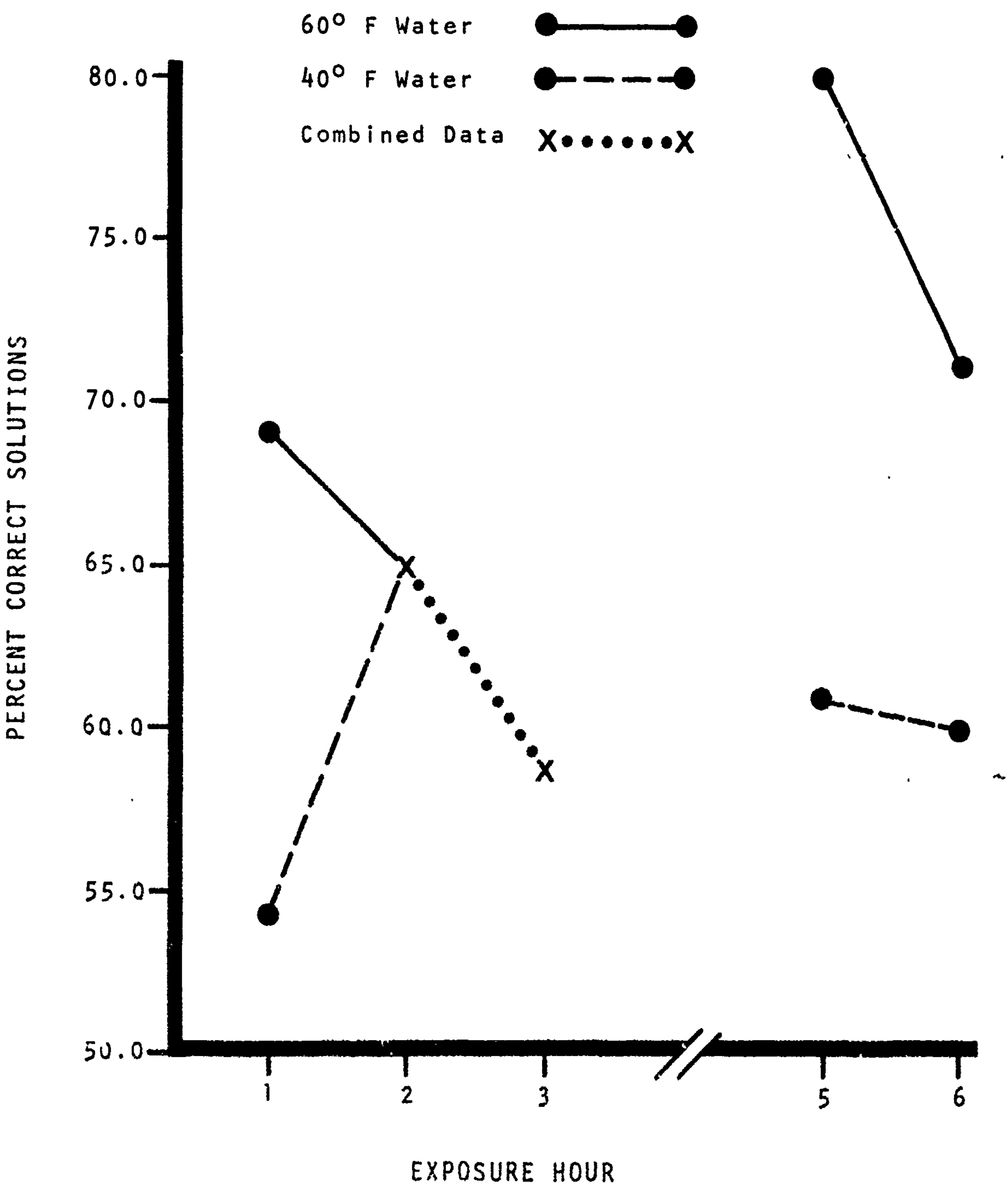
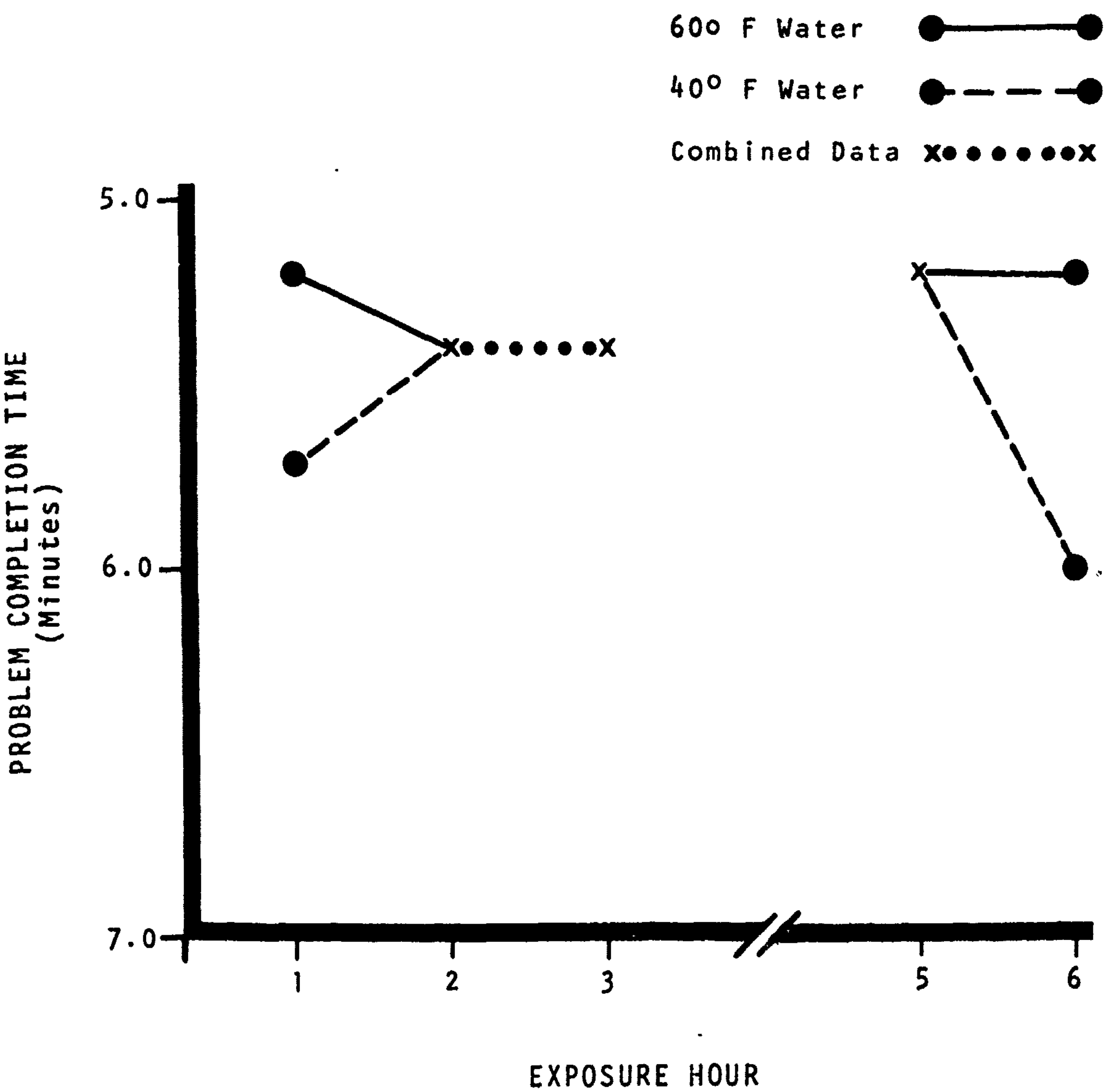


Figure 23

NAVIGATION PROBLEM - SOLVING TIME



2. In-air tasks

a) Force production. Within two minutes of their exit from a 3-hour water exposure, the test divers performed strength tests using the one-hand and two-hand dynamometer: first with the two-hand device and then with the grip strength device using both preferred and non-preferred hands. The men then progressed through the remainder of the in-air test scenario, and, approximately one hour later, performed the strength test series again. It was expected that strength tests would indicate deterioration in performance at water exit vis-a-vis baseline measures, and that strength would to some extent recover as a function of the one-hour work period during which the diver's skin and core-temperatures rose toward initial values. Baseline values were the maximum scores achieved in tests administered on six separate occasions during training.

Table 5 presents a summary of performance on the three strength tests for the baseline condition and following 3-hour 60°F and 40°F water exposures; tabled values are the means of the eight test divers. The two exposure conditions were assessed for significance as contributors to differences in performance deterioration. Results of all statistical tests between water conditions were insignificant; therefore, the data were combined and presented in Figure 24. Differences between mean baseline values and mean scores attained immediately upon water exit were all statistically significant. Hand grip strength essentially recovered to baseline levels after one hour in air; two-hand compression strength recovery was less complete with a mean recovery of approximately 50% of the 9-pound loss attributable to cold-water exposure.

b) Map problem-solving. A two-part map problem was administered to the test divers following completion of the strength tests and approximately five minutes from the time they exited the water. Part A consisted of a 3-leg route to the objective and Part B was a 3-leg route from the objective to the rendezvous point. Both parts were of similar

Table 5. Performance in Force Production Tasks

A. Two-Hand Compression Strength (pounds of force)

Exposure Condition	Baseline	At Water Exit	After 60 Min. in Air
3 hours in 60°F water	146	135	142
3 hours in 40°F water	146	139	141

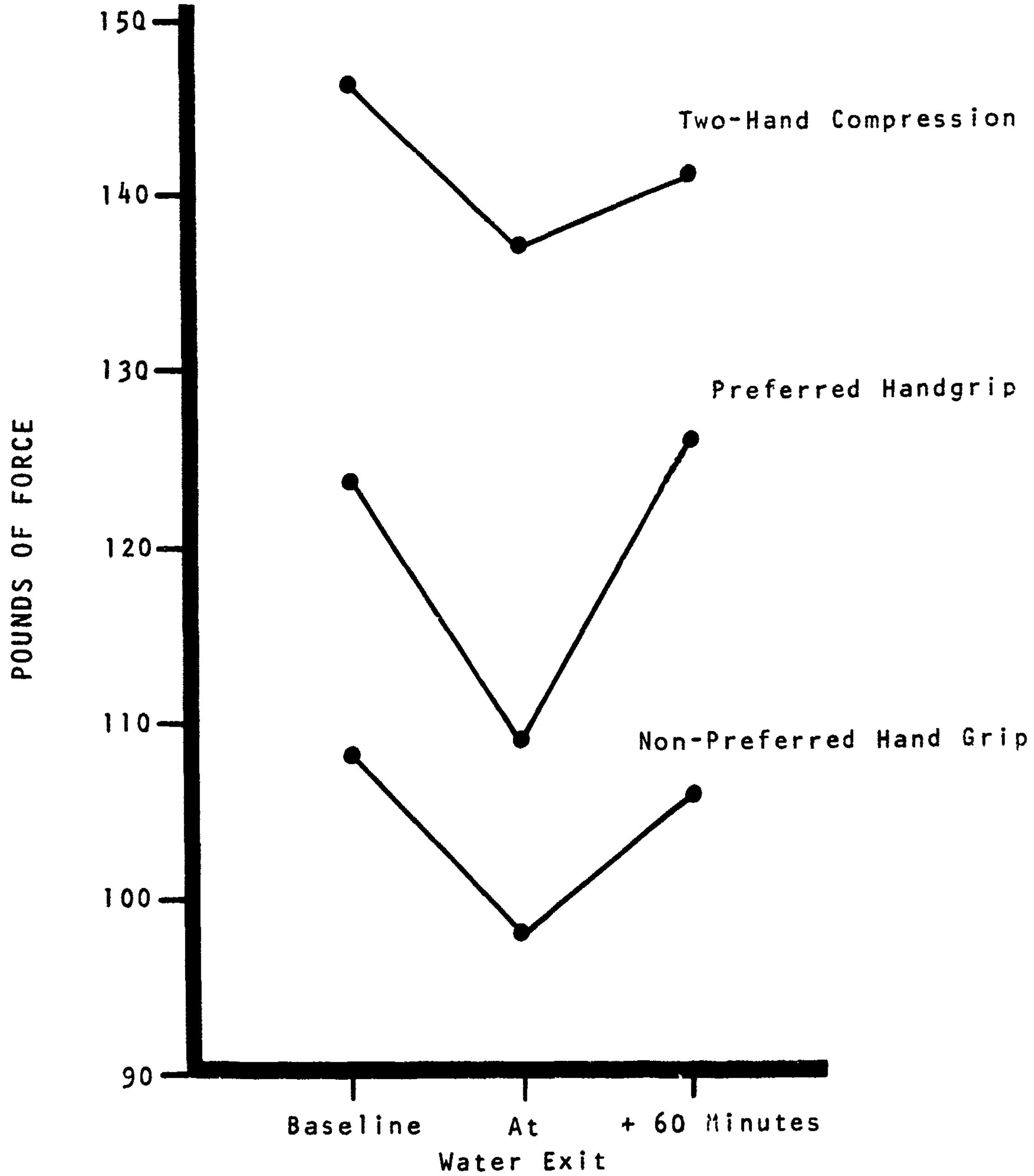
B. Preferred Hand Grip Strength (pounds of force)

Exposure Condition	Baseline	At Water Exit	After 60 Min. in Air
3 hours in 60°F water	124	113	128
3 hours in 40°F water	124	104	123

C. Non-Preferred Hand Grip Strength (pounds of force)

Exposure Condition	Baseline	At Water Exit	After 60 Min. in Air
3 hours in 60°F water	108	101	106
3 hours in 40°F water	108	96	105

Figure 24
ONE-AND TWO-HAND COMPRESSION STRENGTH



format and required common measurements and calculations. Since each test diver completed two map problems in each exposure condition, 72 items were scored for accuracy and the percentage correct used as the accuracy index. Problem completion time was recorded as the nearest 1/100th minute required to complete both parts of the problem.

Table 6 presents both accuracy and time aspects of map problem-solving following the 40° and 60°F water exposures and permits comparison with baseline measures taken as end-of-training criterion values with no prior water exposure.

Table 6. Performance in Map Problem-Solving

Performance Dimension	Baseline (no prior water exposure)	After 3 Hours in water at 60°F	After 3 Hours in water at 40°F
Accuracy (percentage correct of 72 operations)	91.2	79.7	81.4
Time (minutes to completion)	6.96	6.99	6.95

Statistical tests of the significance of differences in scores as a function of exposure condition were negative for both accuracy and time performance dimensions. The two sets of scores were then combined and compared to the baseline values. The combined accuracy index was 80.6% which was significantly different from the 91.2% baseline; but the time indices were not different: the men performed the 2-part map problem in just under 7 minutes for the baseline and for the exposure conditions.

c) Radio firing device assembly. The assembly of the firing device was a 2-man coordinated operation that involved finger dexterity and procedures-following. The task was well learned during the training program and mean rigging-time for the four pairs was 2.1 minutes at the end of training. During the in-air phase of the test scenario, this task was performed following the strength tests, the map problem administration, and the bicycle ergometer work sessions. Time of the performance of this task was approximately thirty minutes after water exit. Core and skin temperatures were on the rise due to the exercise sessions. Each pair rigged the firing device twice in each exposure condition, and in no case was there a procedural error. Average rigging time for the control exposure condition was 1.6 minutes and for the cold exposure condition, 1.8 minutes. None of the time differences was significant.

IV. SUMMARY AND DISCUSSION

Objectives of the research program were to determine effects of long-duration cold exposure on in-water and in-air tasks derived from Naval Inshore Warfare operations involving Swimmer Delivery Vehicles. Four pairs of test divers made two runs in each of two 6-hour test scenarios: a cold scenario and a control scenario. In the cold scenario, water temperature was 4.5°C (40°F) and air temperature was 10°C (50°F). The control scenario temperatures were 15.5°C (60° F) and 20° C (68°F) respectively. Both test scenarios involved a 3-hour in-water phase, a 1-hour in-air phase, and a 2-hour in-water phase followed by a rewarm phase. Tasks in the in-water phases represented those of an SDV pilot/navigator; tasks during the in-air phase were representative of the requirements of a demolition raid. Effects of the cold vs control exposure conditions were of interest in four areas: physiological effects, in-water task performance effects, in-air task performance effects, and post-exposure rewarming effects.

A. Physiological Effects

The relationships between cold water exposure and physiological responses were straightforward. At a given water temperature, core and skin temperatures progressively decreased with exposure time, core temperature at a negatively accelerating rate and skin temperature at a positively accelerating rate. Heart rate fell quickly from an initially high value at water entry to an asymptote approximating the resting level; and, the divers suffered minor loss of weight over the period of exposure.

Differences in water temperature (40°F vs 60°F) produced clear cut effects upon these same physiological responses. Skin temperatures at upper arm, medial thigh and mid-back locations each reflected the differences in the conditions of exposure. In general, skin temperature differences between the 40°F and 60°F water exposures progressed in magnitude as a function of time: differences in the third exposure hour were greater than in the second hour, and second hour differences were greater than the first. By the sixth hour, mean skin temperatures were 21.6°C vs 28.4°C at the upper arm, 26.7°C vs 29.5°C at the medial thigh, and 33.0°C vs 34.3°C at the mid-back sites for the 40°F vs 60°F exposure conditions.

Core temperature profiles also clearly reflected the differences in exposure temperature, although the magnitude of the effect was less pronounced than for the skin temperatures. Of special significance to the later discussion of performance effects was the lack of difference between the core-temperature profiles during the first 90 minutes of exposure. By the end of the third hour, exposure temperature differences were reflected by an absolute difference in mean core-temperature of 0.1°C and a relative fall from initial temperature of 0.2°C. Within 5-10 minutes of water exit, core temperatures fell dramatically to lows of 36.2°C and 36.3°C respectively, then rose to above normal values as a result of the work performed during the in-air phase of the test scenario. Core temperatures fell again during the fifth and sixth hours and throughout this time period, the profile associated with the colder water was consistently lower than the profile for the 60°F water. Magnitude of the differences during these final two hours was on the order of 0.1° to 0.2°C, and final core temperatures at the 360th minute of the overall test scenario were 36.5°C for the cold condition and 36.7°C for the control condition.

Other physiological consequences of the differences in environmental temperature between the cold vs control conditions were an increase in weight loss of 0.7 pound, and higher heart rates throughout the 6-hour cold exposure scenario. Overall, average heart rate for the cold condition was 80 bpm or 23 bpm over resting level, while for the control condition these values were 72 bpm and 15 bpm respectively.

Skin temperatures, core temperature, weight loss and heart rate phenomena all served to quantify the physiological effects of the differences in exposure conditions between the cold and the control test scenarios. Although the differences in each variable were consistently in the expected direction and statistically significant, their magnitudes, with the exception of skin temperature effects, were less than anticipated and from the standpoint of physiological significance, the effects of the two exposure conditions may have been equivalent.

B. In-Water Task Performance Effects

In water at 60°F, hour-to-hour indices of performance effectiveness consistently followed the core and skin temperature profiles. Performance levels were high in the first hour, progressively decreased during the second and third, improved in the fifth hour (following the in-air break and consequent warming) to levels approximating the first hour's performance, then fell again during the sixth. This general pattern held for each performance dimension: signal detection percentage, signal detection latency, choice reaction accuracy, navigation problem-solving accuracy and time.

In water at 40°F, the pattern of performance was similar to that described for 60°F water, except for one consistent and significant difference--the first hour's level of performance was always poorer than the second, and in some cases, even poorer than the third hour's performance level. Following this low point, performance improved during the second hour and generally became coincident with the performance pattern of the 60°F water exposures for the remaining hours. This first-hour effect of the colder water occurred in spite of the prior conditioning of the test divers; each man had experienced 32 hours of training in the water phases of the test scenario, the last 20 hours of which had been conducted in

50°F water. Furthermore, this first-hour effect occurred in spite of the lack of differences in core temperature. As core temperature differences, although slight, appeared during the second and third hours, performance levels became equivalent.

A third notable observation about in-water performance was the significant increase in navigation problem-solving time during the sixth hour in the 40°F water, and the incidence of omissions in problem-solving components occurring in the later hours of the 40°F exposure and not at all in the 60°F water. The navigation problem-solving task represented the higher order cognitive task category and performance on these dimensions was expected to be most sensitive to core temperature differences. These differences were on the order of 0.1° - 0.2°C during the third, fifth and sixth hours and performance differences on the navigation problem-solving dimensions did occurr, although not consistently. This result does suggest, however, that somewhat greater differences in core temperature may have effected more consistent differences in this performance area. The omission phenomena, however, was consistent in occurring only during the later hours of the 40°F water exposures.

C. In-Air Task Performance Effects

Two of the in-air scenario tasks, the strength tests, and the map problem-solving task, were performed within 10 minutes of exit from the water when mean core temperatures were at their lowest: 36.3°C in the control condition and 36.2° C in the cold condition. Performance in both of these task areas was reduced as compared to baseline levels taken with no prior water exposure, but there were no differences in performance attributable to the two water exposures and the consequent differences in body core temperature. Two-hand compression strength was reduced 6%, grip strength was reduced 12%, and map problem-solving accuracy was reduced by 10% as compared to baseline performance levels. Differential effects of exposure on 2-hand vs 1-hand compression is most likely attributable to differences in temperatures of the muscle groups involved (Egstrom et. al., 1973).

Following the initial fall in core temperature upon water exit, the divers warmed as a consequence of the heavy exercise called for in the in-air scenario. Tasks performed during these later stages of the in-air scenario showed no deterioration relative to baseline performance levels. Radio firing device assembly procedures and times were not affected by the exposures, and re-administration of the strength tests at the end of the in-air phase revealed a recovery to baseline levels.

D. Rewarming Methods

Differences in the severity of the cold exposure over the 6-hour test scenario affected the extent of core temperature fall during rewarming. Mean fall was 0.5°C following the cold condition and 0.3°C following the control condition when divers rewarmed in an ideal rewarming environment: 40° C (104°F) water bath. Time of recovery to a core temperature of 37°C (98.6°F) was approximately thirty minutes for both the cold and control conditions of prior exposure.

When divers rewarmed in a hot-air, 38°C (100°F) environment, the extent of fall in mean core temperature was not different from that experienced in hot-water rewarming. Following the 6-hour, 4.5°C water, 10°C air exposure regimen, the average diver lost 0.5°C in the hot-water rewarm and 0.5°C in the hot-air rewarm environments. Time of recovery, however, was longer for the air rewarm procedure; divers requiring an average of 28 minutes to rewarm in hot water required 52 minutes in hot air.

These results suggest that for a given cold exposure, rewarming in hot air lengthens the period required for recovery, but does not increase the extent of the post-immersion fall in core temperature vis-a-vis hot water rewarming. An important part of the hot air rewarming procedure was to quickly undress the diver and get him dry. During one set of dives, slow removal of the wet suit was tried, but this procedure kept the diver wet, further prolonging the recovery period due to evaporative cooling.

E. Interpretation of Results

Overall assessment of results suggests three phenomena accounting for cold stress-task performance relationships. First, is distraction, which accounts for initial decrement in performance under extreme and unfamiliar conditions of exposure. In every task area measured, performance in the 40^{o} F water was significantly less effective than in the 60^{o} F water during the first hour of exposure. Performance decrement in the presence of stressful environmental conditions but with no measurable differences in intervening physiological events was earlier described by Teichner (1957, 1958). Teichner (1958) found significant decrement in a reaction time task in the presence of cold air and high wind velocities independent of any differences in skin temperature. Teichner explained these results by the "distraction hypothesis," the idea that the environment provides competing stimuli which interfere with responses elicited by task-related stimuli. He further distinguished between physiological and psychological cold tolerance, the latter defined as a resistance of the individual to the distracting power of the environment. Bowen (1968) and Stang and Wiener (1970) have similarly explained test results. Presumably, the test divers in the present study achieved psychological adaptation to water at 50^{o} F and were susceptible to distraction at 40^{o} F. As their performance during the second and following hours approximated the 60^{o} F water data, some short-term psychological accommodation presumably occurred. Distraction thus accounts for performance degradation as a consequence of short-term psychological adaptation to the cold, the extent of the behavioral disruption being a function of adaptation levels achieved by the test diver during previous exposures, his general anxiety level, etc. Distraction is hypothesized as principally a psychological, attentional phenomenon, but may be related to rapid rates of change occurring in heat-conserving physiological events.

A second phenomenon is discomfort, which accounts for gradual decrement in performance over long-duration exposure to a generally uncomfortable environment, where a part of the discomfort is attributable to skin and deep body cooling beyond normally acceptable values. The initial phase of the cold water exposure effect, psychological accommodation, is accomplished and the environment is presumably under control. Performance during the discomfort phase is gradually reduced in effectiveness due to the combined effects of cold, fatigue, boredom, vacillating attention and other concomitants of long-duration, repetitive task-situations.

The third phenomenon is dysfunction, which accounts for intermittent response failures or omissions. This phenomenon is different from the previous two in that the nature of performance decrement is qualitative rather than quantitative, and physiologically rather than psychologically based. The diver is presumably well-accommodated to the environmental conditions so that distraction is no longer operant. The task or elements of the task are not performed at all, not just performed more slowly or less accurately as during the discomfort phase.

The omission or blocking phenomena was previously reported by Bowen (1968), associated with performance on a problem-solving task, The Set Exceptions Test. Number of omissions progressively increased as exposure temperatures decreased. Vaughan and Swider (1972) also noted the failure-to-respond syndrome associated with long-term cold water exposure in a diver whose core temperature was 35.9°C. The occurrence of intermittent response blocking is hypothesized as diagnostic of hypothermic progression toward more serious behavioral events such as hallucination, disorientation, and eventual response failure along a broader spectrum of behavioral dimensions.

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APPENDIX A
SAMPLE NAVIGATION AND MAP PROBLEMS

I. NAVIGATION PROBLEM-SOLVING TASK

A. Problem Development

Underwater navigation was selected as a problem-solving situation which would be relevant to operational SDV missic ıs and which could be adapted to the SDV simulator environment. Since the typical navigation solution involves measurement, plotting and arithmetic computations, this type of problem-solving situation appeared particularly adaptable to quantitative performance measurement.

An operational situation that arises in the navigation of a submersible is that of currents which affect an undersea vehicle's actual track across the ocean bottom. Given positional information, current set and drift can be determined by plotting known vectors. Since vectors represent force in both direction and magnitude, they can be used to represent known directions and speed, intersection points and relationships between the vectors. Using known vector information to develop a vector triangle, the navigator is able to determine a vehicle course correction that will carry the SDV over an intended track. Such a generalized current vector problem has operational validity in terms of SDV missions along with providing a problem-solving situation that yields quantifiable data based on a navigator's ability to accurately construct and plot a vector triangle using a scaled ruler and protractor. Proper identification and measurement of vector angles and lengths will result in a solution to the current vector problem.

A problem format was developed that would meet certain constraints imposed by the SDV simulator and the operating environment:

1) The area of the navigator workstation in the rear of the SDV limited the size of the plotting sheets and response forms that could be handled. The plotting sheets in turn determined the vector scales and

distances that could be plotted.

2) Since the solutions to the vector problems would be plotted and recorded in the water, the plotting sheets and response forms were laminated in plastic and treated so that they could be written on underwater.

3) The wet suit three-finger gloves used by the diver subjects limited fine hand and finger dexterity. This limitation necessitated that the design of the problem format minimize lengthy written calculations and intricate plotting. Scale rulers and protractors used for plotting the vector triangles were modified by increasing their thickness to 3/4 inch so that they could be handled and operated with a gloved hand.

4) Vehicle speeds, current set and drift, and travel distance had to be compatible with the input and output capabilities of the Doppler navigation simulator.

B. Doppler Navigation Simulator

The Doppler navigation simulator system is an electronic device designed to provide simulated track information to the SDV navigator. The device consists of two major components: 1) The navigator's display unit and 2) The experimenter control and display unit.

1. Navigator Display Unit. The navigator display is contained in a watertight aluminum housing with a 12-inch diameter display face. The display face contains five digital displays:

- Yds along course. A 5-digit readout representing in yards the intended path of SDV travel from one fixed point to another relative to the surface.

. Yds across course - A 5-digit readout representing in yards the deviation from the intended track in direction and distance perpendicular to the intended track. The first digit of the readout shows direction, right (R) or left (L) of the intended track. The remaining four digits indicate distance in yards that the SDV deviates perpendicular to track.

. Time on leg - A four digit display indicating time of travel on a given course in minutes and tenths of minutes.

. Course A-The direction in which the SDV is to be steered from 000° through 360° for intended track "A."

. Course B - The direction in which the SDV is to be steered from 000° through 360° for intended track "B." Where more than two tracks are required for a mission, the navigator sets in the third track leg on Course A, fourth track leg on Course B, etc.

Controls provided on the navigator display include:

. Course A and Course B selector controls - Three individual rotary controls for Course A and Course B displays enabling navigator to manually set required course on either display to any direction from 000° to 360°.

. Display system activate - Three position rotary selector providing Course A Activate-Reset-Course B Activate functions. Reset position retains the along- and across-course displays and time-on-leg display in a zero condition. Positioning the control to either Course A or Course B activates the time-on-leg continuous-timer and the along- and across-track error displays according to the rates selected by the problem contro.. on the experimenter console. Positioning the control from either Course A or Course B to Reset will reset the three variable navigator displays to zero in readiness for a new course leg run.

2. Experimenter Control and Display Unit. The experimenter console is a surface-operated portable control and display unit connected by wire to the navigator display unit. The experimenter console is provided with the same digital readouts shown on the navigator's display. In addition, the experimenter console has provision for controlling the rate of the along-course and across-course error shown on the navigator display along with the direction of the across-course error. Variable rate-control of along-

course error can be set from 100 to 200 yd/min. in ten-yard increments. Across course error can be set from 10 to 50 yds./min. in one-yard increments. A selector switch for direction of across course error either to the left or right of intended track is also provided. Main power to the entire simulator system is controlled from the experimenter's control console.

C. Vector Problem Format

The current vector problem was designed to be performed in twenty minutes with each problem run concurrently with a twenty minute course leg. At the end of twenty minutes the SDV operator would go to a new course leg and a new vector problem would be initiated. The SDV navigator was provided with a separate laminated plastic plotting sheet and response from for each problem. The base course for each course leg was recorded on the plotting sheet. SDV speed was maintained constant at 6 knots. For each twenty-minute course leg, nine minutes was devoted to display-monitoring and recording along course and across course SDV positions at 3, 6, and 9-minute increments. The remaining eleven minutes was used to solve the current vector problem and order a corrected SDV course to compensate for the current set and drift.

Procedures for a vector problem solution are shown in Table A1.

Table A1

Current Vector Problem Procedures for
Problem Controller and SDV Navigator

Doppler Navigation Simulator Surface Problem Controller	SDV Navigator
1. Enter appropriate rates for along course and across course for Leg #1 course.	1. Set course select to reset position.
2. Switch main power to on position.	2. Enter Leg #1 course in Course A display; enter Leg #2 course in Course B display.
	3. Communicate Leg #1 course to SDV operator.
3. Note problem start; activate mission clock.	4. Switch select control to Course A starting problem.
	5. Monitor along course, across course and time on leg displays.
	6. Record along course and across course SDV positions at times 03 minutes 06 minutes 09 minutes.
4. Monitor display for problem completion and navigator entry of corrected SDV course.	7. Plot vector triangle and solve for: . SDV course over ground . SDV speed over ground . Current set . Current drift . Corrected SDV course Record answers on response form.

Doppler Navigation Simulator
Surface Problem Controller

5. Observe entry of corrected SDV course, record problem completion time.

6. Enter appropriate rates for along course and across course error for Leg #2 course.

SDV Navigator

8. Enter corrected SDV course on display.

9. Order corrected SDV course to SDV operator.

10. Monitor time on leg display.

11. At time 20 minutes switch select control to reset and then to Course B.

12. Order Leg #2 course to SDV operator.

D. Sample Problem

Input Data to SDV Navigator

SDV Course (Track) 245°.

SDV Speed of Advance 6 knots.

Inputs to Problem Controller

Along Course Error Rate = 120/yds/min.

Across Course Error Rate - RIGHT 56 yds/min.

SDV Navigator Procedures for Vector Problem Solution

1. Navigator notes SDV course and speed of advance on plotting sheet and response form (Figure A1 and Figure A2).

2. Enter SDV course 245° on Course A on the Doppler navigation simulator display (DNSD) and start problem by switching control lever from Reset to Course A.

3. True course line represented by center vertical line on plotting sheet represents the SDV intended track of 245°. Plots marked on intended track and labeled as 03, 06, and 09 represent the projected SDV positions at 3-minute intervals assuming no effect of current on either SDV course or speed.

4. Using the continually updated along-course and across-course data provided by the DNSD, record on response form the actual SDV position at 03 minutes, 06 minutes, and 09 minutes. At time 09 minutes, the following actual track positions are recorded:

Time	Along-Track Position	Across-Track Position
03	360	R168
06	720	R336
09	1080	R504

5. Using the along-track and across-track positions recorded from the DNSD, plot on plotting sheet the actual SDV position at times 03 minutes, 06 minutes, and 09 minutes (shown in sample problem as points G, F and E). Use 1/20 scale on the engineer's rule. Each mark on the scale equals 10 yards.

6. Draw a line starting at point A through the position plots at times 03, 06 and 09 minutes. The resulting line AE represents the SDV actual course and speed vector, and shows the SDV track as it was affected by the current.

7. Connect the intended track positions with the actual track positions at the three equivalent time plots. The resulting lines BG for time 03, CF for time 06 and DE for time 09 represent the current direction and speed vectors.

8. To obtain the actual SDV course, place the protractor origin at point A with the SDV course of 245° along the intended track line AD. Read SDV course over ground (COG) on the actual track line AE. For the sample problem course over ground is 270°.

9. Actual SDV speed (speed over ground, SOG) is obtained by measuring the length of the actual speed vector (line AG) from time 00 minutes to time 03 minutes on the 1/20 scale of the engineer's rule. Each unit on the rule represents 1/10 knot. For the sample problem, SOG is 4 knots.

10. Current direction (current set) is obtained by placing the protractor at point E and measuring the angle a. Place the SDV intended track (245°) along the actual track line EA (in the direction E ⟶ A) and read current set along the current vector ED. Current set is 005° in the sample problem.

11. Current speed (current drift) is represented by the length of the current vector BG and is measured on the 1/20 scale on the engineer's rule. For the sample problem the current drift is 3 knots.

12. To obtain the command course for current correction, the protractor is placed at point A with the true course of 245° indicated along the actual track line AE and the command course is read on the protractor along the intended track line AD. For the sample problem the command heading is 220°.

Figure A-1. Generalized Vector Problem (Plotting Sheet)

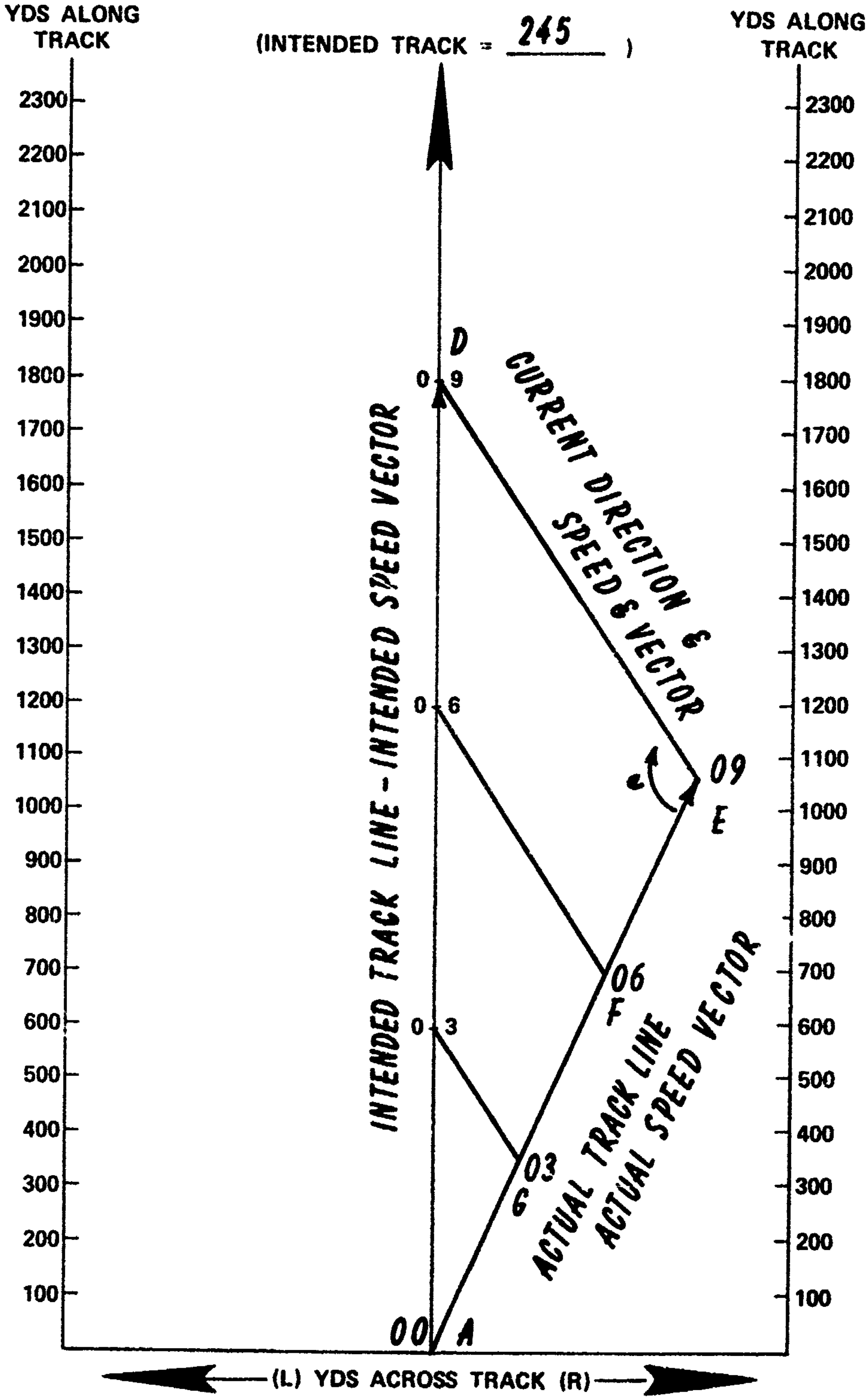

Figure A-2. Generalized Vector Problem (Response Form)

GENERALIZED VECTOR PROBLEM
(RESPONSE FORM)

GIVEN INFORMATION:

SDV COURSE (TRACK) 245 DEGREES

SDV SPEED OF ADVANCE 6 KNOTS

PLOT ACTUAL TRACK POSITION INPUTS FROM DNSD:

TIME	ALONG TRACK POSITION	ACROSS TRACK POSITION
03	360	R168
06	720	R336
09	1080	R504

FIND:

SDV COURSE OVER GROUND (COG) 270 DEGREES

SDV SPEED OVER GHOUND (SOG) 4 KNOTS

CURRENT SET 005 DEGREES

CURRENT DRIFT 3 KNOTS

CORRECTED SDV COURSE 220

ENTER ON DNSD

II. MAP PROBLEM-SOLVING TASK

A. Problem Development

The abstract map problem was incorporated into the overall in-air scenario to test SDV operators in problem-solving abilities following prolonged cold water exposure. Mission profiles indicate that SDV operations may require SDV personnel to leave their vehicle and transit on foot to a designated objective area.

Such inland penetrations require skills in setting up compass courses, map reading, scale interpretations and conversions, and time/speed/distance. calculations. As such the abstract map problem was determined to be ideally suited as a problem-solving task that could test rule-following and arithmetic abilities of the subject personnel under conditions following environmental stress.

To maintain the problem-solving situation in an operational context the abstract map problem was developed in two parts. The first part consisted of a three-leg compass course originating at a starting point, passing through two checkpoints and then proceeding to an objective point. The second part of the problem originates at the objective, passes through two checkpoints and continues on to a rendezvous point. Each part of the problem can be used individually or presented as a combined problem.

B. Problem Format

The abstract map problem consists of two plotting sheets A and B, and two response forms A and B. Form A contains problem phase 1 (transit from starting point to objective area) and Form B contains problem phase 2 (return transit from objective point to rendezvous point).

The problem sheets each contain an 8 x 10 grid (A to H and 1 to 10). Printed on each sheet is the orientation of north and the four reference points required for solution of the problem reference points are connected to show direction of transit route.

The response forms each contain step-by-step procedures for problem solution along with the following information: map scale in miles/inch, rate of march in mph. and starting time in four digits (hours and minutes). The values assigned to the given information are different for each map problem so that the subjects learn the procedures and not the answers.

Given the plotting sheet grids, response forms, pencil, ruler and protractor, the subject learns a 5-step solution procedure as follows:

Step 1: Convert inches to miles for each transit leg from start to objective or from objective to rendezvous. Measure length of each transit leg in inches and tenths. Multiply each of the leg lengths by the map scale. Add together the results to obtain the total travel distance in miles from start to objective or from objective to rendezvous. (3 measurement operations, 3 multiplication calculations, 1 addition calculation.)

Step 2: Convert miles per leg to travel time. For the distances in miles obtained for each leg (Step 1) divide by the rate of march in MPH to obtain the travel time for each leg in hours and tenths of hours. Add the three travel times together to obtain the total travel time from start to objective or from objective to rendezvous (3 division calculations, 1 addition calculation).

Step 3: Convert hours and tenths of hours to hours and minutes. Using the total travel time obtained in Step multiply tenths of hours by 60 to obtain minutes for total travel time in hours and minutes (1 multiplication calculation).

Step 4: Find estimated time of arrival (ETA) at objective in clock time. Add total travel time from Step 3 to starting time given. If minute in sum is greater than 60, subtract 60 from minutes portion and add one hour to hours portion. Result is ETA in clock time (2 addition calculations, 1 subtraction calculation).

Step 5: Find compass heading for each course leg. Using protractor and the north orientation shown on plotting sheet, measure the compass heading of each of the three transit legs from start to objective or from objective to rendezvous (3 measurement operations.)

A summary of the map problem task requirements in terms of measurement operations and arithmetic calculations is hown in Table A2.

Table A2. Map Problem Task Requirements

	Measurement	Arithmetic Calculations			
	Operations	Addition	Subtraction	Division	Multiplication
Step #1	3	1	0	0	3
Step #2	0	1	0	3	0
Step #3	0	0	0	0	1
Step #4	0	2	1	0	0
Step #5	3	0	0	0	0
Totals Start-Objective	6	4	1	3	4
Totals Obj.-Rdv.	6	4	1	3	4
Overall	12	8	2	6	8

C. Sample Problem

A complete sample problem for both Part A (start to objective) and Part B (objective to rendezvous) follows.

Figure A-3. Generalized Map Problem
Part A (Grid Sheet)

Name ______________________ Rank _________ Date _________

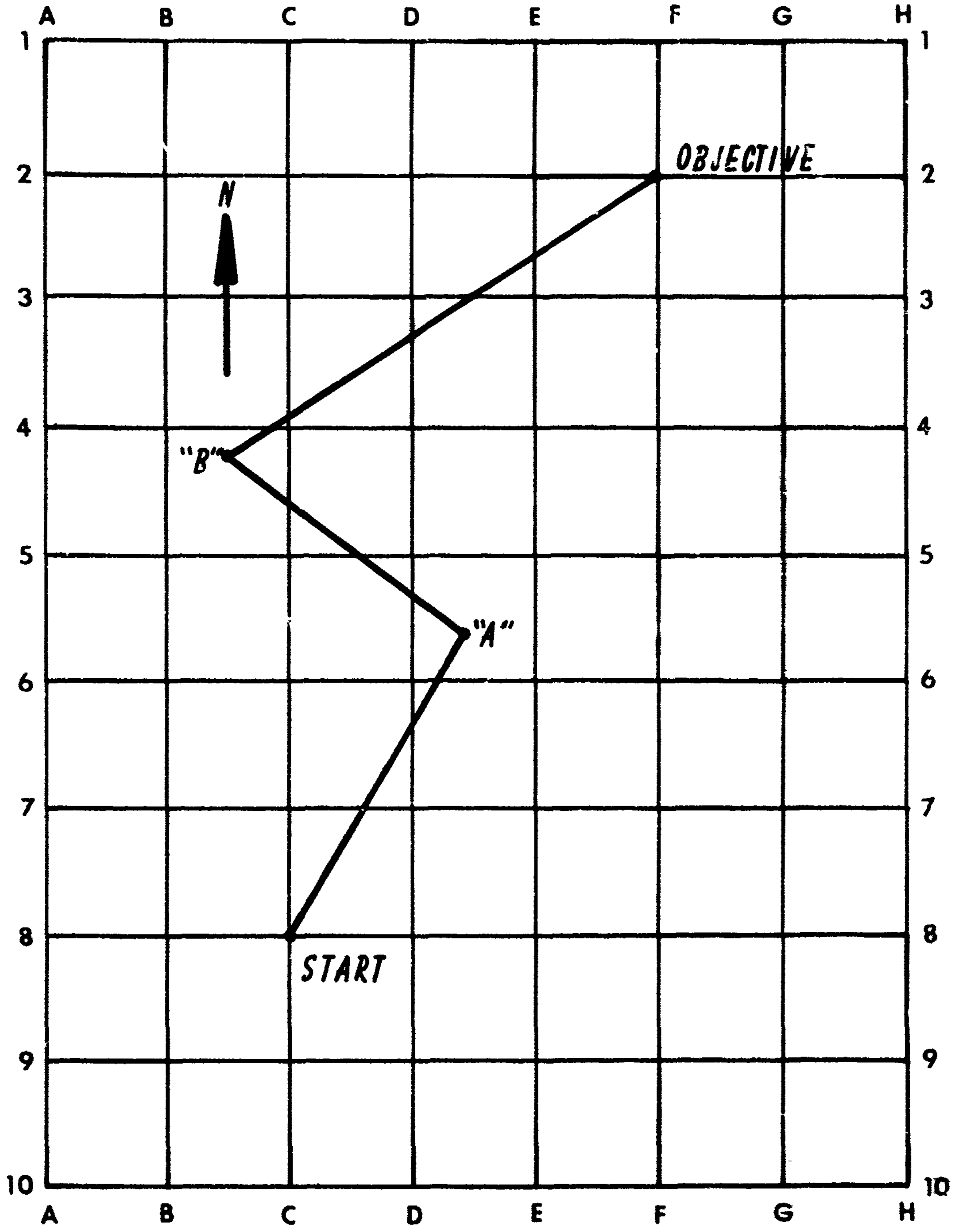

Figure A-4. Generalized Map Problem (Response Form A)

1 CONVERT INCHES TO MILES FOR LEGS START-OBJECTIVE

LEG	LENGTH IN INCHES		MAP SCALE MILES/INCH		MILES/LEG
START TO "A"	2.9	×	3	=	8.7
"A" TO "B"	2.4	×	3	=	7.2
"B" TO OBJECTIVE	4.1	×	3	=	12.3
				+	
TOTAL TRAVEL DISTANCE START TO OBJECTIVE					28.2

2 CONVERT MILES/LEG TO TRAVEL TIME

LEG	MILES/LEG		RATE OF MARCH (MPH)		TRAVEL TIME/LEG (HOURS)
START TO "A"	8.7	÷	4	=	2.2
"A" TO "B"	7.2	÷	4	=	1.8
"B" TO OBJECTIVE	12.3	÷	4	=	3.1
				+	
TOTAL TRAVEL TIME START TO OBJECTIVE					7.1

3 CONVERT HRS & TENTH OF HRS TO HOURS AND MINUTES

TOTAL TRAVEL TIME HRS AND TENTH OF HRS	TENTH OF HOURS				MINUTES	TOTAL TRAVEL TIME IN HRS AND MIN.
7.1	.1	×	60	=	6	7 HRS 6 MIN

4 FIND ETA AT OBJECTIVE IN CLOCK TIME

START TIME

08:59

TRAVEL TIME

+ 7:06

15:65

15:65

\- :60

15:05

\+ 1

16:05 ETA

5 FIND COMPASS HEADING FOR EACH LEG USING PROTRACTOR AND NORTH ORIENTATION

LEG	COMPASS HEADING
START → "A"	032°
"A" → "B"	306°
"B" → OBJECTIVE	058°

Figure A-5. Generalized Map Problem
Part B (Plotting Sheet)

Name ______________ Rank ________ Date ________

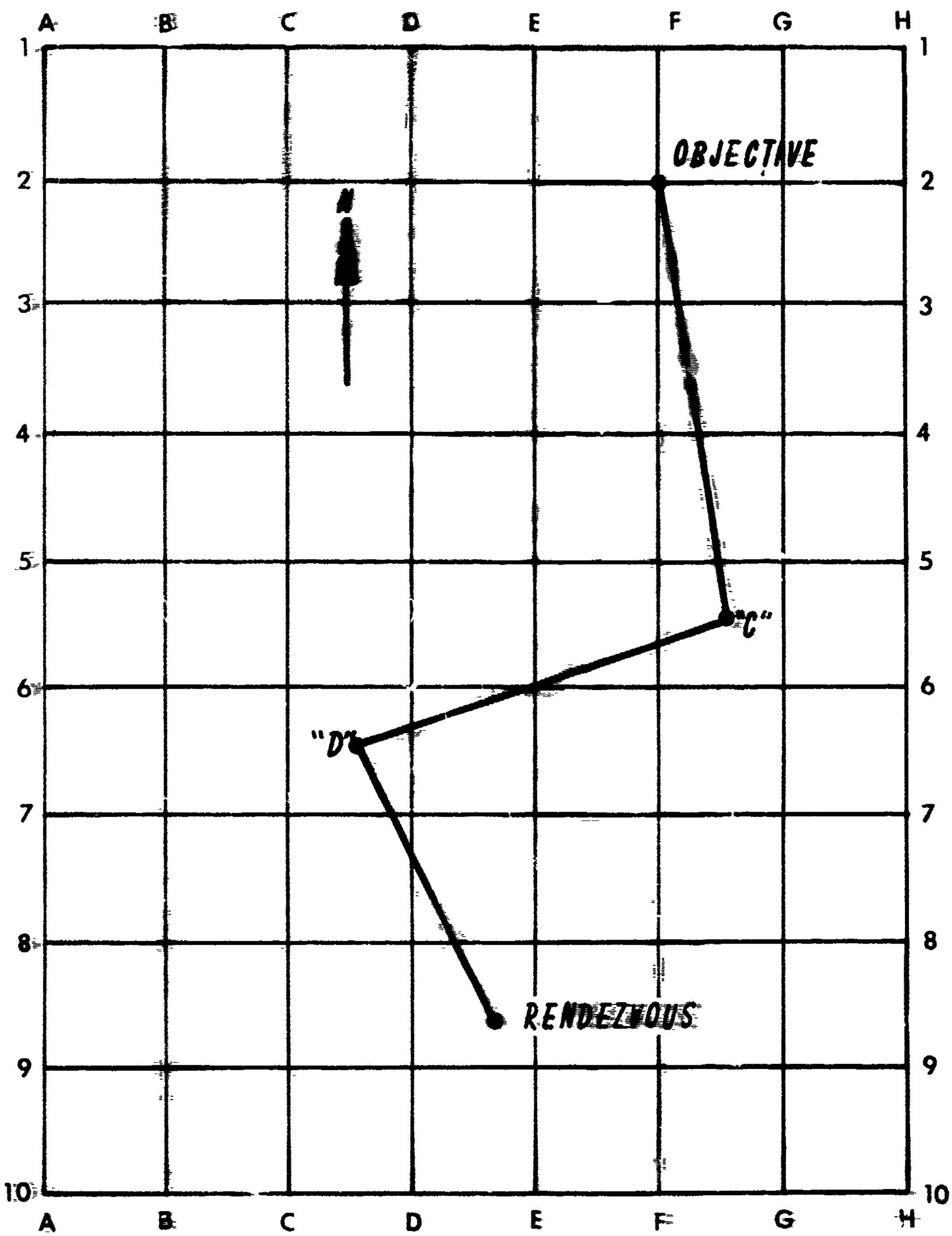

Figure A-6. Generalized Map Problem
Part B (Response Form B)

1 CONVERT INCHES TO MILES FOR LEGS OBJECTIVE TO RENDEZVOUS

LEG	LENGTH IN INCHES		MAP SCALE MILES/INCH		MILES/LEG
OBJECTIVE TO "C"	a1 3.5	x	a2 4	=	a3 14.0
"C" TO "D"	b1 3.2	x	b2 4	=	b3 12.8
"D" TO RENDEZVOUS	c1 1.5	x	c2 4	=	c3 6.0
				+	
			TOTAL TRAVEL DISTANCE OBJECTIVE TO RDV.		c4 32.8

2 CONVERT MILES/LEG TO TRAVEL TIME

LEG	MILES/LEG		RATE OF MARCH (MPH)		TRAVEL TIME/LEG (HOURS)
OBJECTIVE TO "C"	d1 10.5	÷	d2 5	=	d3 2.1
"C" TO "D"	e1 9.6	÷	e2 5	=	e3 1.9
"D" TO RENDEZVOUS	f1 4.5	÷	f2 5	=	f3 0.9
				+	
			TOTAL TRAVEL TIME OBJECTIVE TO RDV.		g1 4 . g2 9

3 CONVERT HRS & TENTH OF HRS TO HOURS AND MINUTES

TOTAL TRAVEL TIME HRS AND TENTH OF HRS	TENTH OF HOURS				MINUTES	TOTAL TRAVEL TIME IN HRS. AND MIN.
g1 4 . g2 9	g2 9	x	g3 60	=	g4 54	g1 4 HRS g4 54 MIN

4 FIND ETA AT RENDEZVOUS IN CLOCK TIME

START TIME

	h1 16:38	h3 20:92
TRAVEL TIME		
+	g1 4 : g4 54	− h4 :60
	h2 20:92	h5 20:32
		+ h6 1
		h7 21:32 ETA

5 FIND COMPASS HEADING FOR EACH LEG USING PROTRACTOR AND NORTH ORIENTATION

LEG	COMPASS HEADING
OBJ. → "C"	i1 117°
"C" → "B"	i2 250°
"D" → RDV.	i3 134°

APPENDIX B

BASIC DATA TABLES

APPENDIX B. BASIC DATA TABLES

I. PHYSIOLOGICAL DATA

A. Skin Temperatures (°C): cell entries are means of 2 runs

Table B-1. Mean Hourly Skin Temperatures (upper arm) for Cold Exposure Condition

Test Diver	Exposure Hour						
	Start	1	2	3	4	5	6
1	-	-	-	-	-	-	-
2	30.3	25.5	21.8	20.4	24.5	22.8	20.3
3	32.5	26.4	26.0	25.3	27.8	23.8	19.4
4	31.5	25.7	20.6	19.3	23.6	22.7	20.4
5	31.8	27.1	24.6	23.4	26.3	24.4	23.1
6	34.0	27.4	24.1	23.5	27.8	23.5	22.3
7	32.0	25.8	23.0	22.0	26.7	24.0	20.6
8	32.5	28.7	26.0	26.1	30.3	26.2	24.8
Mean	32.1	26.7	23.7	22.9	26.7	23.9	21.6

Table B-2. Mean Hourly Skin Temperatures (upper arm) for Control Exposure Condition

Test Diver	Exposure Hour						
	Start	1	2	3	4	5	6
1	-	-	-	-	-	-	-
2	32.0	29.4	28.0	27.4	30.0	28.6	27.0
3	34.3	31.4	30.1	29.7	32.9	31.4	30.4
4	32.4	29.7	27.7	26.7	29.8	28.5	27.8
5	31.3	29.8	29.1	28.7	29.8	29.3	28.3
6	32.3	30.2	28.5	27.9	29.5	28.9	27.5
7	32.0	31.3	30.2	29.4	32.2	30.4	29.2
8	31.5	30.2	29.0	28.6	31.0	29.9	28.7
Mean	32.3	30.3	28.9	28.3	30.7	29.6	28.4

Table B-3. Mean Hourly Skin Temperatures (medial thigh) for Cold Exposure Condition

Test Diver	Exposure Hour						
	Start	1	2	3	4	5	6
1	32.5	28.1	28.4	27.4	31.2	25.7	27.6
2	30.5	26.6	25.4	24.1	28.3	27.2	27.2
3	32.8	31.6	29.3	27.7	31.8	30.3	28.9
4	32.8	29.3	27.5	25.7	30.6	28.7	26.1
5	32.5	27.7	27.0	27.2	31.1	27.8	27.1
6	31.0	25.3	26.0	24.9	26.3	21.4	23.5
7	32.2	29.6	28.0	27.5	30.7	29.5	26.8
8	31.8	28.4	27.7	27.6	29.8	28.3	26.5
Mean	32.0	28.3	27.4	26.5	30.0	27.4	26.7

Table B-4. Mean Hourly Skin Temperatures (medial thigh) for Control Exposure Condition

Test Diver	Exposure Hour						
	Start	1	2	3	4	5	6
1	33.0	30.4	29.5	29.6	31.9	29.1	29.5
2	28.0	28.0	27.8	27.9	29.4	28.3	28.4
3	34.5	32.7	31.7	30.9	33.4	32.0	30.9
4	33.0	30.0	29.4	28.7	31.1	30.2	29.0
5	31.7	30.2	30.2	29.0	31.5	29.9	29.7
6	31.0	30.6	29.2	28.4	30.4	29.8	28.8
7	31.7	31.4	30.6	30.2	32.0	31.6	30.3
8	32.3	31.1	30.8	30.3	32.0	30.4	29.3
Mean	31.9	30.6	29.9	29.4	31.5	30.2	29.5

Table B-5. Mean Hourly Skin Temperatures (mid-back) for Cold Exposure Condition

Test Diver	Exposure Hour						
	Start	1	2	3	4	5	6
1	35.0	34.6	34.5	33.5	34.8	33.3	32.8
2	35.0	33.8	32.0	31.0	32.6	32.3	31.3
3	35.0	34.8	34.5	34.5	35.0	34.4	34.3
4	34.5	33.6	32.1	31.9	33.3	32.2	31.3
5	35.0	34.3	34.0	33.8	34.7	34.0	33.6
6	35.0	34.6	34.5	33.9	34.8	34.0	33.6
7	35.0	34.2	33.6	33.6	34.9	34.3	33.9
8	34.5	34.3	33.6	33.4	34.9	34.1	33.2
Mean	34.9	34.3	33.6	33.2	34.4	33.6	33.0

Table B-6. Mean Hourly Skin Temperatures (mid-back) for Control Exposure Condition

Test Diver	Exposure Hour						
	Start	1	2	3	4	5	6
1	35.0	35.0	35.0	34.8	35.0	34.9	34.6
2	34.5	35.0	34.5	34.4	34.8	35.0	34.4
3	35.0	35.0	35.0	34.6	35.0	34.7	34.4
4	35.0	35.0	34.2	34.0	34.8	34.6	34.0
5	34.9	34.4	34.2	34.0	34.9	34.5	34.0
6	35.0	35.0	35.0	34.7	35.0	35.0	34.8
7	35.0	34.7	34.5	34.5	33.8	33.8	33.8
8	35.0	34.2	34.2	34.1	34.7	34.3	34.1
Mean	34.9	34.8	34.6	34.4	34.8	34.6	34.3

B. Core Temperatures (°C): Cell Entries are Means of 2 Runs

Table B-7. Core Temperatures at Selected Intervals During the 6-Hour Cold Exposure Condition

Exposure Phase	Time (mins.)	Test Diver								
		1	2	3	4	5	6	7	8	Mean
In-water at 4.5°C (40°F)	00	37.2	37.6	37.3	37.2	37.1	37.2	37.5	37.2	37.3
	10	37.6	-	37.4	37.4	37.3	-	37.5	37.3	37.4
	20	37.6	-	37.3	37.4	37.2	-	37.4	37.3	37.4
	30	37.5	37.5	37.3	37.3	37.0	36.8	37.4	37.2	37.2
	60	37.0	37.4	37.1	37.0	36.8	36.7	37.2	37.0	37.0
	90	36.9	37.3	37.0	36.9	36.6	36.7	37.0	36.9	36.9
	120	36.8	37.0	37.0	36.8	36.4	36.6	36.9	36.8	36.8
	150	36.6	36.8	37.2	36.7	36.4	36.6	36.8	36.8	36.7
	180	36.5	36.7	37.0	36.6	36.4	36.6	36.8	36.8	36.7
In-air at 10°C (50°F)	185	-	35.8	36.4	35.9	35.8	-	36.5	36.4	36.1
	190	36.2	36.2	36.6	36.1	35.7	36.7	36.5	36.4	36.3
	200	36.3	36.6	36.8	36.5	35.9	36.8	36.6	36.8	36.5
	210	36.6	36.9	37.0	36.6	36.1	36.6	36.7	37.0	36.7
	220	36.9	37.1	37.1	37.0	36.4	37.3	37.0	37.2	37.0
	230	36.9	37.3	37.5	-	36.5	37.4	37.1	37.3	37.1
	240	36.9	37.4	37.5	37.3	36.6	37.2	37.1	37.3	37.2
In-water at 4.5°C (40°F)	270	36.8	37.5	37.2	37.2	36.6	36.8	37.1	37.3	37.1
	300	36.8	37.3	-	36.7	36.4	36.6	-	37.0	36.8
	330	36.4	37.2	-	36.6	36.2	36.4	36.8	36.8	36.6
	360	36.4	36.9	36.6	36.4	35.9	36.4	36.7	36.7	36.5

Table B-8. Core Temperatures at Selected Intervals During the 6-Hour Control Exposure Condition

Exposure Phase	Time (mins.)	Test Diver								
		1	2	3	4	5	6	7	8	Mean
In-water at 15.5°C (60°F)	00	37.2	37.2	37.0	37.3	37.0	37.5	37.2	37.2	37.2
	10	37.3	37.3	37.2	37.4	37.0	37.5	37.4	37.4	37.3
	20	37.2	37.3	37.2	37.2	37.0	37.5	37.4	37.2	37.2
	30	37.2	37.3	37.0	37.2	36.9	37.4	37.4	37.2	37.2
	60	36.9	37.2	36.8	37.1	36.6	37.2	37.3	37.2	37.0
	90	36.9	37.2	36.7	36.9	36.4	37.1	37.2	37.1	36.9
	120	36.8	37.2	36.8	36.7	36.4	37.1	37.1	36.9	36.9
	150	36.6	37.0	36.8	36.8	36.4	37.1	36.9	36.9	36.8
	180	36.6	37.0	36.7	36.8	36.4	37.1	36.9	37.0	36.8
In-air at 20°C (68°F)	190	36.2	36.3	36.5	35.8	36.3	36.8	36.2	36.8	36.4
	200	36.5	36.8	36.6	-	36.1	36.9	36.3	36.9	36.5
	210	36.7	36.9	-	36.3	36.5	37.2	36.6	37.1	36.8
	220	36.9	37.2	36.8	36.9	37.0	37.5	37.1	37.4	37.1
	230	36.9	37.3	37.3	37.3	37.0	37.7	37.3	37.4	37.3
	240	37.1	37.5	37.4	37.4	37.0	37.8	37.5	37.4	37.4
In-water at 15.5°C (60°F)	270	37.0	37.3	37.2	37.2	36.8	37.5	37.3	-	37.2
	300	36.7	37.1	36.9	37.0	36.6	37.3	37.1	37.0	36.9
	330	36.6	36.9	36.3	36.9	36.5	37.0	37.0	-	36.7
	360	36.6	37.0	36.3	36.9	36.4	36.9	36.9	36.7	36.7

Table B-9. Core Temperatures During Rewarming Phase
Following the 6-Hour Cold Exposure Condition

9-A. Hot-Water Rewarm Method

Post-dive time (mins.)	Test Diver							
	1	2	3	4	5	6	7	8
00	36.4	37.0	36.8	36.4	36.3	36.6	36.5	36.6
05	36.2	36.8	36.6	36.0	35.8	36.6	36.0	36.4
10	36.0	36.6	36.3	35.8	35.8	36.5	35.9	36.6
15	35.7	36.6	36.4	35.7	35.7	36.3	35.9	36.8
20	35.7	36.7	36.7	36.4	36.6	36.3	36.3	37.0
25	35.8	36.8	37.1	36.7	36.9	36.4	36.6	
30	36.0	37.0		37.1	37.1	36.6	36.7	
35	36.5					36.8	37.0	
40	37.2					37.1		

9-B. Hot-Air Rewarm Method

Post-dive time (mins.)	Test Diver							
	1	2	3	4	5	6	7	8
00		36.7	36.6	36.4	35.6		36.9	36.8
05		36.4	36.5	36.0	35.5		36.6	36.6
10		36.3	36.4	35.9	35.4		36.2	36.4
15		36.3	36.3	36.2	35.3		36.1	36.5
20		36.4	36.3	36.3	35.4		36.0	36.6
25		36.6	36.3	36.3	35.5		36.1	36.7
30		36.7	36.4	36.6	35.6		36.5	36.8
35		37.0	36.5	36.8	35.7		36.8	36.9
40			36.7	37.0	35.9		37.0	37.0
45			-		36.2			
50			36.8		36.3			
60			36.9		36.5			
70			37.0		36.6			
80					36.8			
90					37.0			

Table B-10. Core Temperatures During Rewarming Phase Following the 6-Hour Control Exposure Condition

10-A. Hot-Water Rewarm

Post-dive time (mins.)	Test Diver							
	1	2	3	4	5	6	7	8
00	36.8	36.9	36.3	36.6	36.4	36.8	36.8	36.7
05	36.4	-	36.3	36.6	36.1	36.7	36.6	36.5
10	36.3	-	36.3	36.5	36.1	36.8	36.5	36.5
15	36.6	-	36.2	36.4	36.1	36.9	36.4	36.5
20	36.8	36.9	36.6	36.6	36.2	36.9	36.4	36.5
25	36.9	37.0	36 8	37.0	36.3	37.0	36.7	36.6
30	37.2		37.0		36.5		37.0	36.6
35					36.8			36.7
40					37.2			36.9
45								37.0

10-B. Hot-Air Rewarm

Post-dive time (mins.)	Test Diver							
	1	2	3	4	5	6	7	8
00	36.3	37.0	37.0	37.0	36.5	36.9	36.9	36.6
05	36.2	37.0	36.9	36.8	36.5	36.6	36.4	36.5
10	36.3	37.2	36.9	36.7	36.4	36.7	36.4	36.6
15	36.4		36.8	36.7	36.3	36.7	36.4	36.7
20	36.5		36.8	36.7	36.2	36.7	36.4	36.7
25	36.5		36.8	36.7	36.4	36.8	36.4	36.8
30	36.6		36.7	36.6	36.4	36.8	36.4	36.9
35	36.6		36.8	36.6	36.4	36.8	36.4	36.9
40	36.6		36.8	36.6	36.4	36.9	36.4	36.9
50	36.6		36.9	36.6	36.4	36.9	36.5	37.0
60	37.0		37.0	36.7	36.4	37.0	36.6	
65				-	-		36.8	
70				36.8	36.4		36.9	
80				36.8	36.4		37.0	
90				37.0	37.0			

C. Pill Passing Time (Hrs: mins.)

Table B-11. Radiosonde Pill Passing Time

Pill administration	Test Diver							
	1	2	3	4	5	6	7	8
1	48:30	24:15	59:20	32:50	47:20	25:00	25:15	25:10
2	31:35	14:15	51:00	52:00	59:50	12:20	24:15	62:20
3	49:00	-	51:45	29:15	29:45	11:45	13:45	50:05
4	-	-	74:00	26:15	28:00	-	23:00	26:00
Mean	43:02	19:15	59:01	35:05	41:04	16:21	21:34	40:54

D. Heart Rates

Table B-12. Mean Hourly Heart Rate During Water Phases of Cold Exposure Condition

Test Diver	Resting H/R	Exposure Hour					
		Start	1	2	3	5	6
1	56	115	91	76	90	86	79
2	72	97	80	70	59	73	69
3	58	104	78	79	81	78	83
4	52	78	68	74	67	68	70
5	53	109	75	74	74	81	79
6	64	110	88	86	81	86	86
7	40	83	66	61	62	66	64
8	63	90	80	82	85	84	81
Mean	57	98	78	75	75	78	76

Table B-13. Mean Hourly Heart Rate During Water Phases of Control Exposure Condition

Test Diver	Resting H/R	Exposure Hour					
		Start	1	2	3	5	6
1	56	113	80	71	67	77	66
2	72	91	80	73	68	86	69
3	58	95	80	63	65	85	70
4	52	60	64	57	64	65	55
5	53	94	71	61	64	75	65
6	64	97	79	73	69	85	75
7	40	74	61	53	54	59	50
8	63	87	77	62	66	72	62
Mean	57	89	74	64	65	76	64

E. Weight Loss (pounds)

Table B-14. Weight Loss as a Function of Differences in Exposure Conditions

Test Diver	Control Conditions			Cold Conditions		
	1st run	2nd run	Mean	1st run	2nd run	Mean
1	1.50	2.00	1.75	2.00	-	2.00
2	.50	2.25	1.38	3.75	1.00	2.38
3	5.25	2.50	3.88	3.50	5.00	4.25
4	4.50	2.50	3.50	4.25	5.50	4.88
5	2.50	.50	1.50	2.00	.25	1.13
6	1.50	0.0	.75	1.25	-	1.25
7	1.25	0.0	.63	2.00	2.50	2.25
8	4.50	.50	2.50	3.50	3.25	3.38
Mean			1.99			2.69

II. PERFORMANCE DATA

A. Vigilance Monitoring and Response

Table B-15. Percentage of Obstacle Signals Detected During 40° F Water Exposures

Test Diver	Exposure Hour				
	1	2	3	5	6
1	100.0	-	-	-	-
2	83.3	87.5	75.0	-	-
3	83.3	100.0	100.0	71.4	87.5
4	100.0	100.0	100.0	66.7	44.4
5	83.3	100.0	50.0	100.0	88.9
6	100.0	100.0	87.5	100.0	88.9
7	100.0	100.0	100.0	100.0	100.0
8	83.3	100.0	100.0	100.0	100.0
Mean	91.6	98.2	87.5	89.7	85.0

Table B-16. Percentage of Obstacle Signals Detected During 60° F Water Exposures

Test Diver	Exposure Hour				
	1	2	3	5	6
1	100.0	87.5	75.0	100.0	66.7
2	100.0	100.0	87.5	85.7	100.0
3	100.0	87.5	87.5	100.0	66.7
4	100.0	100.0	85.7	57.1	66.7
5	100.0	100.0	87.5	85.7	88.9
6	100.0	100.0	75.0	85.7	44.4
7	100.0	100.0	100.0	100.0	100.0
8	100.0	100.0	100.0	100.0	55.6
Mean	100.0	96.9	87.3	89.3	73.6

Table B-17. Mean Acquisition Time (minutes) for Signals Detected During 40 °F Water Exposures

Test Diver	Exposure Hour 1	2	3	5	6
1	.13	-	-	-	-
2	.10	.15	.14	-	-
3	.08	.08	.10	.09	.09
4	.05	.05	.10	.08	.12
5	.08	.10	.09	.10	.13
6	.05	.06	.10	.05	.13
7	.09	.06	.06	.05	.05
8	.09	.06	.09	.10	.13
Mean	.08	.08	.10	.08	.11

Table B-18. Mean Acquisition Time (minutes) for Signals Detected During 60 °F Water Exposures

Test Diver	Exposure Hour 1	2	3	5	6
1	.04	.11	.12	.09	.18
2	.06	.07	.07	.09	.06
3	.06	.07	.07	.08	-
4	.07	.10	.08	.08	.04
5	.10	.07	.11	.04	.20
6	.03	.06	.10	.09	.09
7	.08	.05	.05	.05	.04
8	.06	.07	.08	.04	.16
Mean	.06	.08	.08	.07	.11

Table B-19. Percentage of Correct Responses to Detected Signals During 40°F Water Exposures

Test Diver	Exposure Hour 1	2	3	5	6
1	100.0	-	-	-	-
2	80.0	100.0	100.0	-	-
3	60.0	100.0	100.0	100.0	100.0
4	100.0	100.0	87.5	75.0	75.0
5	100.0	75.0	75.0	100.0	87.5
6	100.0	75.0	85.7	85.7	37.5
7	83.3	100.0	100.0	71.4	88.9
8	80.0	100.0	87.5	85.7	100.0
Mean	87.9	92.9	90.8	86.3	81.5

Table B-20. Percentage of Correct Responses to Detected Signals During 60°F Water Exposures

Test Diver	Exposure Hour 1	2	3	5	6
1	83.3	85.7	100.0	100.0	83.3
2	100.0	100.0	71.4	100.0	100.0
3	83.3	100.0	85.7	85.7	50.0
4	100.0	100.0	100.0	100.0	83.3
5	100.0	100.0	71.4	100.0	100.0
6	100.0	100.0	100.0	83.3	100.0
7	87.5	100.0	100.0	100.0	100.0
8	100.0	87.5	100.0	85.7	80.0
Mean	94.3	96.6	91.1	94.3	87.1

Table B-21. Vigilance Monitoring and Response Performance During a One-Hour 50°F Water Exposure

Test Diver	Detection Percentage (%)	Detection Latency (mins.)	Choice Reaction Accuracy (%)
1	90.0	.080	88.9
2	90.0	.094	100.0
3	100.0	.036	90.0
4	100.0	.088	100.0
5	100.0	.100	100.0
6	100.0	.063	100.0
7	87.5	.061	90.0
8	80.0	.076	100.0
Mean	93.4	.075	96.1

B. Navigation Problem-Solving

Table B-22. Navigation Problem-Solving Accuracy During 40°F Water Exposures

Test Diver	Exposure Hour				
	1	2	3	5	6
1	40.0	46.7	53.3	40.0	73.3
2	46.7	53.3	46.7	66.7	60.0
3	80.0	80.0	80.0	60.0	73.3
4	26.7	60.0	60.0	60.0	53.3
5	60.0	93.3	66.7	60.0	60.0
6	60.0	40.0	-	-	-
7	53.3	93.3	46.7	73.3	66.7
8	66.7	66.7	46.7	66.7	33.3
Mean	54.2	66.7	57.2	61.0	60.0

Table B-23. Navigation Problem-Solving Accuracy
During 60° F Water Exposures

Test Diver	Exposure Hour 1	2	3	5	6
1	66.7	40.0	46.7	66.7	33.3
2	46.7	40.0	66.7	66.7	73.3
3	100.0	86.7	93.3	80.0	86.7
4	73.3	80.0	80.0	93.3	73.3
5	80.0	60.0	60.0	73.3	66.7
6	46.7	40.0	46.7	73.3	66.7
7	73.3	86.7	66.7	100.0	80.0
8	66.7	73.3	33.3	86.7	93.3
Mean	69.2	63.3	61.7	80.0	71.7

Table B-24. Navigation Problem-Solving Time
During 40° F Water Exposures

Test Diver	Exposure Hour 1	2	3	5	6
1	6.3	5.8	5.5	5.0	5.6
2	5.8	5.4	5.9	6.2	5.3
3	5.4	6.0	4.7	4.8	5.0
4	6.2	5.3	5.7	4.9	7.5
5	6.0	6.6	7.5	6.6	7.4
6	5.8	6.4	-	-	-
7	5.0	4.5	4.4	4.9	4.9
8	5.0	5.1	5.3	5.2	6.4
Mean	5.7	5.6	5.6	5.4	6.0

Table B-25. Navigation Problem-Solving Time During 60°F Water Exposures

Test Diver	Exposure Hour				
	1	2	3	5	6
1	4.4	4.7	4.4	3.8	4.7
2	4.5	5.4	4.7	5.0	4.3
3	5.3	5.7	5.0	5.5	4.9
4	6.8	7.0	6.4	5.7	7.0
5	4.2	3.6	6.5	5.3	5.3
6	5.6	5.6	5.2	5.2	5.4
7	5.3	5.2	4.8	4.9	4.8
8	5.6	5.1	4.8	5.0	5.1
Mean	5.2	5.3	5.2	5.0	5.2

Table B-26. Navigation Problem-Solving Accuracy and Time During a One-Hour 50°F Water Exposure

Test Diver	Problem-Solving Accuracy (%)	Problem-Solving Time (mins.)
1	40.0	5.0
2	46.7	4.3
3	86.7	6.8
4	66.7	7.7
5	53.3	5.8
6	40.0	5.5
7	93.3	6.0
8	60.0	5.2
Mean	60.8	5.8

C. Force Production (pounds of force)

Table B-27. Two-Hand Compression Strength
Following Three Hours in 40°F vs 60°F Water

Test Diver	Baseline: no prior water exposure	3-Hours in 40°F Water		3-Hours in 60°F Water	
		at water exit	+ 60 mins.	at water exit	+ 60 mins.
1	145	120	125	128	130
2	155	138	145	140	143
3	130	135	140	128	128
4	180	173	165	163	170
5	120	128	130	123	135
6	160	140	145	138	155
7	130	140	135	128	130
8	-	-	-	-	-
Mean	146	139	141	135	142

Table B-28. Preferred Hand Grip Strength Following
Three Hours in 40°F vs 60°F Water

Test Diver	Baseline: no prior water exposure	3 Hours in 40°F Water		3-Hours in 60°F Water	
		at water exit	+ 60 mins.	at water exit	+ 60 mins.
1	113	103	111	89	121
2	120	73	82	106	111
3	139	139	161	136	157
4	134	114	140	127	142
5	128	110	114	114	129
6	113	72	126	112	109
7	111	110	115	113	124
8	137	112	137	106	128
Mean	124	104	123	113	128

Table B-29. Non-Preferred Hand Grip Strength Following Three Hours in 40°F vs 60°F Water

Test Diver	Baseline: no prior water exposure	3-Hours in 40°F Water		3-Hours in 60°F Water	
		at water exit	+ 60 mins.	at water exit	+ 60 mins.
1	110	98	111	90	109
2	85	75	80	96	108
3	124	115	124	118	118
4	112	87	86	95	109
5	105	102	109	99	90
5	108	90	106	95	94
7	100	83	103	95	106
8	117	115	122	117	114
Mean	108	96	105	101	106

D. Map Problem-Solving

Table B-30. Map Problem-Solving Accuracy Following Three Hours in 40°F vs 60°F Water

Test Diver	Baseline: no prior water exposure	3-Hours at 40°F	3-Hours at 60°F
1	91.0	72.2	77.8
2	85.3	79.2	81.9
3	92.0	95.8	88.9
4	88.0	80.6	79.2
5	96.0	76.4	76.4
6	91.0	77.8	80.6
7	92.0	84.7	77.8
8	95.5	84.7	75.0
Mean	91.2	81.4	79.7

Table B-31. Map Problem-Solving Time Following Three Hours in 40°F vs 60 °F Water

Test Diver	Baseline: no prior water exposure	3-Hours at 40°F	3-Hours at 60°F
1	8.00	5.81	6.03
2	10.00	8.67	9.09
3	6.22	7.85	8.00
4	6.22	7.48	7.33
5	7.33	6.25	5.89
6	6.40	5.83	4.93
7	4.25	8.28	8.94
8	7.33	5.43	5.69
Mean	6.96	6.95	6.99

APPENDIX C

SUMMARY OF STATISTICAL SIGNIFICANCE TESTS

I. PHYSIOLOGICAL DIFFERENCES

A. Skin Temperature

1. Mid-Back: Effects of Water Temperature

Difference	df	t	Significance Level
Hour 1.60v40	7	2.69	P<05> 01
Hour 2.60v40	7	3.34	P< 01
Hour 3.60v40	7	3.10	P< 01

B. Heart Rate: Effects of Water Temperature

Difference	df	t	Significance Level
Start 60 v 40	7	2.94	P< 05> 01
Hour 1.60v40	7	2.65	P< 05 > 01
Hour 2.60v40	7	4.16	P< 01
Hour 3.60v40	7	2.82	P< 05> 01
Hour 5.60v40	7	.67	N.S.
Hour 6.60v40	7	6.16	P< 01

C. Weight Loss: Effects of Water Temperature

Difference	df	t	Significance Level
60 v 40	7	3.13	P< 01

II. PERFORMANCE DIFFERENCES

A. Pilot Performance Differences: Effects of Water Temperature

1. Signal Detection Percentage

Differences	df	t	Significance Level
Hour 1.60 v 40	7	2.66	$P < .05 > .01$
Hour 3.60 v 40	7	.46	N.S.
Hour 6.60 v 40	5	1.08	N.S.

2. Signal Acquisition Latency

Differences	df	t	Significance Level
Hour 1.60 v 40	7	1.55	$P < 10 > 05$
Hour 3.60 v 40	6	1.81	$P < 05 > 01$
Hour 5.60 v 40	5	1.08	N.S.

3. Choice Reaction Accuracy

Differences	df	t	Significance Level
Hour 1.60 v 40	7	1.44	$P < 10 > 05$
Hour 5.60 v 40	5	.90	N.S.
Hour 6.60 v 40	5	.26	N.S.

B. Pilot Performance Differences: Effects of Exposure Time

1. Signal Detection Accuracy

Difference	df	t	Significance Level
Hour 2. v Hour 3	7	2.65	P<05>01
Hour 5. v Hour 6	7	1.96	P<05>01

2. Signal Detection Latency

Difference	df	t	Significance Level
Hour 1.60v Hour 2	7	1.40	N.S.
Hour 1.40v Hour 2	7	90	N.S.
Hour 2. v Hour 3_{40}	6	3.90	P<01
Hour 2. v Hour 3_{60}	7		N.S.
Hour 5. v Hour 6	7	2.02	P<05> 01
Hour 1. v Hour 3_{40}	6	1.92	P<05> 01
Hour 1. v Hour 3_{60}	7	1.68	P<10> 05

3. Choice Reaction Accuracy

Difference	df	t	Significance Level
Hour 1.40v Hour 2	7	.93	N.S.
Hour 2. v Hour 3	7	.81	N.S.
Hour 5. v Hour 6	7	1.44	P<10> 05

C. Navigation Performance Differences: Effects of Water Temperature

1. Problem-Solving Accuracy

Difference	df	t	Significance Level
Hour 1.60v40	6	3.15	$P < 01$
Hour 2.60v40	6	.59	N.S.
Hour 3.60v40	6	1.17	N S.
Hour 6.60v40	6	1.12	N.S.

2. Problem-Solving Time

Difference	df	t	Significance Level
Hour 2.60v40	7	.61	N.S.
Hour 3.60v40	6	1.32	N.S.
Hour 5.60v40	6	1.17	N.S.
Hour 6.60v40	6	2.97	$P < 05 > 01$

D. Navigator Performance Differences: Effects of Exposure Time

1. Problem-Solving Accuracy

Difference	df	t	Significance Level
Hour 1 Hour 2	7	.98	N.S.
Hour 1v Hour 3	7	2.96	$P < 05 > 01$

2. Problem-Solving Time

Difference	df	t	Significance Level
Hour 1.40 v Hour 2	7	1.70	$P < 10 > 05$
Hour 5 v Hour 6_{40}	6	3.29	$P < 01$

E. Force Production Differences: Effects of Water Temperature

1. Two-Hand Compression Strength

Difference	df	t	Significance Level
60 v 40	6	1.51	N.S.
Baseline v 60 + 40	6	1.99	$P < 05 > 01$

2. Hand-Grip Strength (preferred hand)

Difference	df	t	Significance Level
60 v 40	7	1.34	N.S.
Baseline v 60 + 40	7	3.78	$P < 01$

3. Hand-Grip Strength (non-preferred hand)

Difference	df	t	Significance Level
60 v 40	7	1.58	N.S.
Baseline v 60 + 40	7	3.63	$P < 01$

F. Map Problem-Solving Differences: Effects of Water Temperature

1. Problem-Solving Accuracy

Difference	df	t	Significance Level
60 v 40	7	.87	N.S
Baseline v 60 + 40	7	4.58	P < 01

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